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PRELIMINARY VIBRATION AND FLUTTER STUDIES ON P-47 TAIL

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NACA

WASHINGTON

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

PRELIMINARY VIBRATION AND FLUTTER STUDIES ON P-47 TAIL

By Theodore Theodorsen

Summary:

This paper contains a brief report illustrated by photographs and vibration records on the failure of the P-47 rudder in the high-speed tunnel at the LMAL at a true speed of 468 miles per hour and a density corresponding to 9000 feet altitude. The fin-rudder unit was tested as being at least representative of the tail design of the P-47 airplane. It is noted that the rudder was subjected to a speed in excess of 400 miles per hour for less than an hour of total testing time.

Introduction:

Proceeding on the assumption that reported accidents on the P-47 tail assembly were due to insufficient rigidity of the tail structure, four distinct investigations were carried out in an attempt to explain the nature of the accidents.

Reprint Note: This report deals with an early design of the P-47 tail (P-47B) and is presented only for the possible interest in the setup and procedure. In the later versions of the P-47 tail, the fabric covering was replaced by metal covering and the airplane did not experience any of the vibration difficulties reported herein.

1. <u>On the effect of air disturbances in the wake of the airplane body at normal and higher angles of attack</u>.- This investigation was carried out in the full-scale tunnel in conjunction with pressure-distribution tests.

2. <u>Vibration tests of the vertical fin-rudder unit to define all lower order vibration modes</u>.- These studies were carried out as soon as the negative results of the test 1 became evident.

3. <u>Theoretical studies on possible higher-frequency flutter modes</u>.- These studies were conducted for the purpose of proving, if possible, that certain responses obtainable under 2 could cause flutter or leave an insufficient margin of safety.

4. <u>Flutter tests on vertical fin-rudder units</u>.- These tests were carried out at full scale and speed in the 8-foot high-speed tunnel.

<u>Tests on Wake Disturbances in the Full-Scale Tunnel:</u>

These tests were run at tunnel velocities of 60 to 85 miles per hour. Fluctuations of the wake were observed at a point behind the rudder and near the center line through the fuselage. The pickups used were (1) hot wires, and (2) wire strain gages of special design. A wire strain gage was also inserted in the rudder surface for the purpose of recording strains in the rudder corresponding to imposed disturbances from the air stream. The outputs from these pickups were

amplified and recorded on an oscillograph. A sample record taken at 85 miles per hour is given in figure 1. The upper trace is obtained on the wire strain gage or "fish tail" and the lower record is taken with a hot-wire pickup, both in the air stream immediately behind the rudder. The timing wave at the bottom is a 300-cycles-per-second sine wave.

These records showed only one outstanding response frequency very nearly of the same rate as the timing wave or 300 cycles per second.

At about 400 miles per hour, such boundary frequency would approximate 1500 cycles per second or 90,000 cycles per minute. The conclusion is that such boundary layer frequency is far too high to excite any dangerous mode in the fin-rudder assembly.

At higher angles of attack, near maximum lift, a lower frequency of about 90 cycles per second was evident in the oscillograph records. It was concluded that also this frequency which corresponded to almost 40,000 cycles per minute was also too high to cause dangerous responses in the tail unit. As regards the magnitude of the forces associated with these two frequencies, some idea was obtained by calibrating the strain element on the rudder for steady and alternating forces in a separate test set-up. It was found that the direct strain measured was small but agreed in order of magnitude with expected values and it was further

found that the maximum alternating strain was approximately one-fourth of the direct strain corresponding to full rudder deflections at the greatest angle of yaw. Briefly, therefore, it can be stated that the body wake does not contain disturbances in the lower frequency range corresponding to the criticals of the structure and that further the power contained in the high wake frequency observed was evidently of insufficient magnitude to cause concern.

Vibration Tests on Fin-Rudder Unit:

In these tests the fin was substantially fixed at the base. The four lowest responses of the fin-rudder unit were measured as follows:

1. Lowest bending	14.8 cycles per second
2. Second bending	37 cycles per second
3. Lowest torsion	53 cycles per second
4. Not defined	75 cycles per second
5. Not defined	94 cycles per second

The appearance of these five lowest responses are indicated on figures 2 to 6, inclusive.

In these figures, the plus and minus signs designate the phase, with the size of the signs approximately indicating the magnitude of the motion at each point. For instance, in figure 2, it can be noted that the entire surface is in the same phase, with the largest deflection near the top as

expected. In the second figure (fig. 3), it is seen that the entire unit again is in phase except for the upper balance weight and the lower rear corner of the rudder.

In the next figure (fig. 4), which case was originally believed susceptible to flutter, it is seen that there is a large deflection near the upper end of the tab. The top balancing weight is out of phase. Responses at 75 and 94 cycles per second were also recorded. (See figs. 5 and 6.)

Flutter Test in High-Speed Tunnel:

The fin rudder was installed in zero angle-of-yaw position. Five strain gages were distributed over the surface for the purpose of insuring a permanent record in case of failure. Two of these gages were of the carbon type, one attached to the fin spar near the base, G, one to the torque tube of the rudder near the control attachment, R, to show torsion in rudder. The other three were wire gages, the gage, Y, along the rib at the upper end of the tab, B, along the rib next above the tab and B_a along the rib just below tab. All gages were glued, taped, and painted on surfaces. In this discussion, the fin rudder is considered in normal attitude although the test unit was installed upside down in the tunnel.

To study the apparent damping of the rudder, the installation was equipped with a trigger arrangement by which the rudder could be instaneously released from a position of

approximately 3° deflection. During the tests, the rudder was in a free-floating condition (except when deflected).

Tests were run throughout the entire range of tunnel speed. Records of the vibrations were taken at approximately 200, 300, 400, 420, 440, and 460 miles.

The rudder failed at 468 miles per hour (true speed). The temperature of the air was $t = 111^\circ$ F and the density $\rho = 0.00182$ pounds per cubic foot. The upper portion of the rudder beyond the tab was demolished, the trailing edge and most of the fabric torn off, and the ribs badly twisted with the upper one torn out. The act of disintegration of the rudder was observed by several persons. It did not appear to be violent probably due to the high frequency involved. Prior to the explosion the rudder appeared rather normal except for a distinct swelling up of the skin between the ribs, most prominent near the base but also evident over the front portion of the tip of the rudder. This swelling started at about 300 miles per hour. The installation was not conveniently arranged for visual observation. Evidently the entire upper section of the rudder swelled up considerably a few seconds before the final destruction. Whether the structure at this time exhibited a possible large amplitude and high frequency vibration, or that it already had broken down, was not evident from observation. The process of destruction lasted only 3 to 5 seconds. The photographs

(fig. 7 through 11) show the destroyed rudder in the tunnel, and figure 12, the rudder separately with the broken pieces of the trailing edge arranged in place by small wires.

Discussion of Vibration Records:

Some of the vibration records obtained during the test are reproduced in figures 13 to 30. For each record is given the approximate tunnel speed. The four traces are from the top down: G, the bending element on the fin, R, the torsion element near the control attachment, Y, the wire strain gage adjacent to the tab, and B, the wire strain gage on the second rib above tab. (The record of the element B_d was discontinued at an early stage.) The element B happened to be the most significant since it was located near the center of the destroyed portion.

It should be noted that these elements were put in somewhat at random; the absolute amplitudes of the various strains are of no particular significance.

The first interesting observation can be made in regard to the apparent rudder damping. The trace, G, shows this most plainly. At zero airspeed (figs. 13(c) and (d)) the records show a small damping as expected. In figure 14, taken at approximately 200 miles per hour, it is noted that the large deflection in G, obtained in each case by releasing the trip mechanism, appears nearly critically damped. In R and B about three successive excursions are visible;

Y shows little response. Records in figures 16 and 17 taken at 300 miles show a similar damping. At 350 miles per hour (fig. 19), the response, B, is still well damped, but the torsion element, B, and the rib element, B, show several successive waves after each tripping of the rudder (figs. 22 to 26).

At approximately 400 miles per hour, there are four to five large peaks appearing in the fin-bending record, G, and evidently similar disturbances in the other three. In other words, the damping is starting to disappear, which fact is significant of the approach to a condition of flutter involving these particular responses. However, flutter in these combinations of lower frequency modes evidently did not develop. It is noted that at about 420 miles per hour (fig. 27) a very high frequency of about 140 cycles per second comes into evidence. At 440 miles per hour (fig. 28) the damping in the low bending appears fairly unchanged but the high frequency of about 140 cycles per second starts to dominate the record.

This high frequency was in evidence probably for 3 to 5 minutes before the failure of the rudder. The final record (fig. 30) was taken at approximately 468 miles per hour true speed (or 410 indicated) about a minute before the rudder was destroyed. It is seen that the element, B, which was situated near the center of the destroyed area, shows an almost pure sine wave. The frequency is by count 146 cycles per second.

Further Vibration Tests to Study Nature of High Frequency Evident in Records of Rudder Failure:

Since the frequency observed in the records of the rudder failure was much higher than the one previously assumed capable of producing flutter, a prototype of the destroyed rudder was subjected to further vibration studies since these high frequencies were not investigated in advance. This high frequency was located at 138 cycles per second and is shown in saw-dust pattern in figure 31. Like most of the higher-mode responses, it cannot conveniently be identified by a simple term.

It might be designated a trailing-edge response since the motion involved deflection of the trailing edge which assumed a sine form with less deflections near the rib attachments. The ribs exhibited essentially pure torsion. The fabric would assume certain square response patterns. The regularity of the pattern was somewhat broken by the tab. The tab free or fixed to the rudder would only change the frequency by a few percent.

The response in this mode is fairly sharp. It was noted however, that a somewhat higher imposed frequency would cause more response toward the base of the rudder.

Theoretical Flutter Studies:

These studies proceeded in conjunction with the other work here reported. They were based on the assumption that

a higher mode of the type shown in figure 4 was involved. The studies showed that not much margin of safety remained against flutter in this mode. Since the records give no evidence of this mode of a frequency of 50 to 60 cycles per second, but showed a higher mode of 146 cycles per second, detail reference to these calculations will be considered unnecessary at the present stage.

Tests on the Rudder Fabric:

Since it was noted during the high-speed tests that the fabric bulged to a considerable extent, in particular near the base of the rudder, it was considered of interest to apply internal pressure to the rudder. The lower portion of the subject rudder was cut off and properly sealed. High-pressure air was applied and the pressure read on a gage. The fabric evidently bulged more at about 2 pounds per square inch than the bulging observed in the high-speed-tunnel tests. At about this pressure, the structure gave away at the point shown by arrow at P in figure 32. The rib below the tab failed in bending due to the pull of the fabric. Although the fabric had been considerably strained in the high-speed test, it did not seem to be much weakened. After the rib collapsed, a leak developed near the corner of the tab at a pressure only slightly higher. The maximum deflection of the fabric between the ribs was about 2/3 inch.

Remarks:

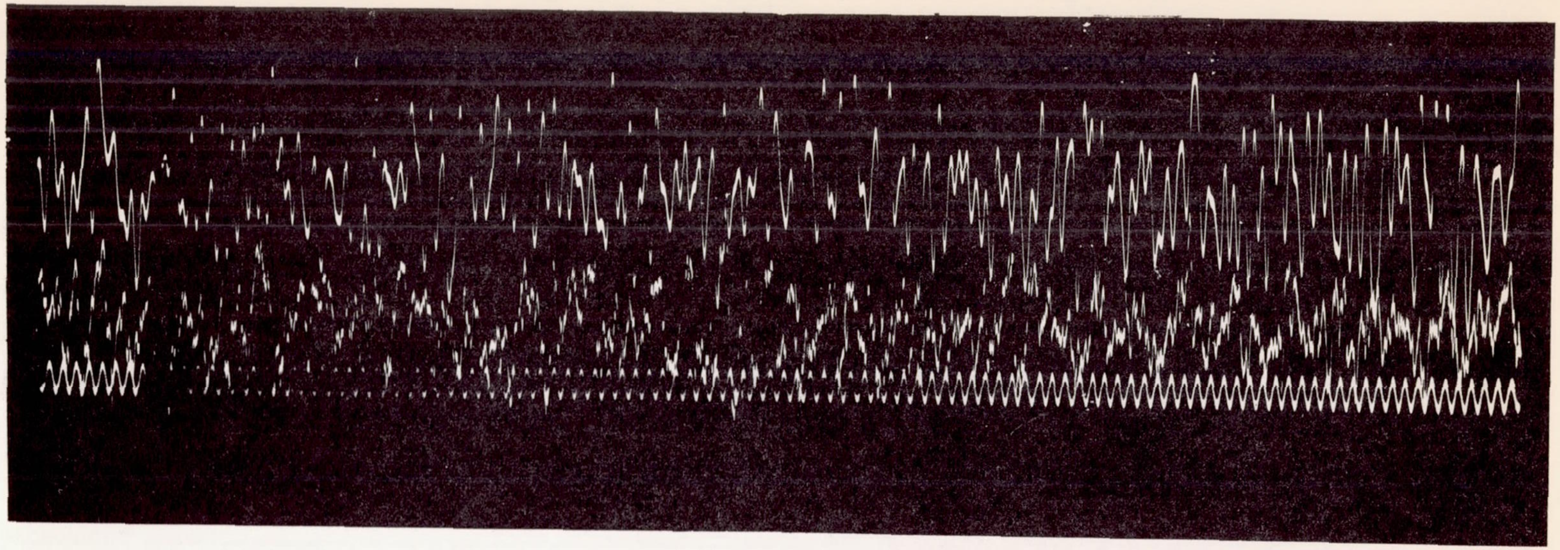
In so far as the exact nature of the destructive forces involved are yet to be established, only a tentative conclusion can be made. It appears that a high-frequency response of the fabric and trailing edge of the rudder was involved in the accident. Vibration test revealed the existence of a response of very nearly the same high frequency of approximately 140 cycles per second. A further test series is scheduled for the purpose of determining the exact nature and cause of the failure.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 21, 1943.

Fish tail
Attenuation, 5

Hot wire
Attenuation, 2

300-cycle timer

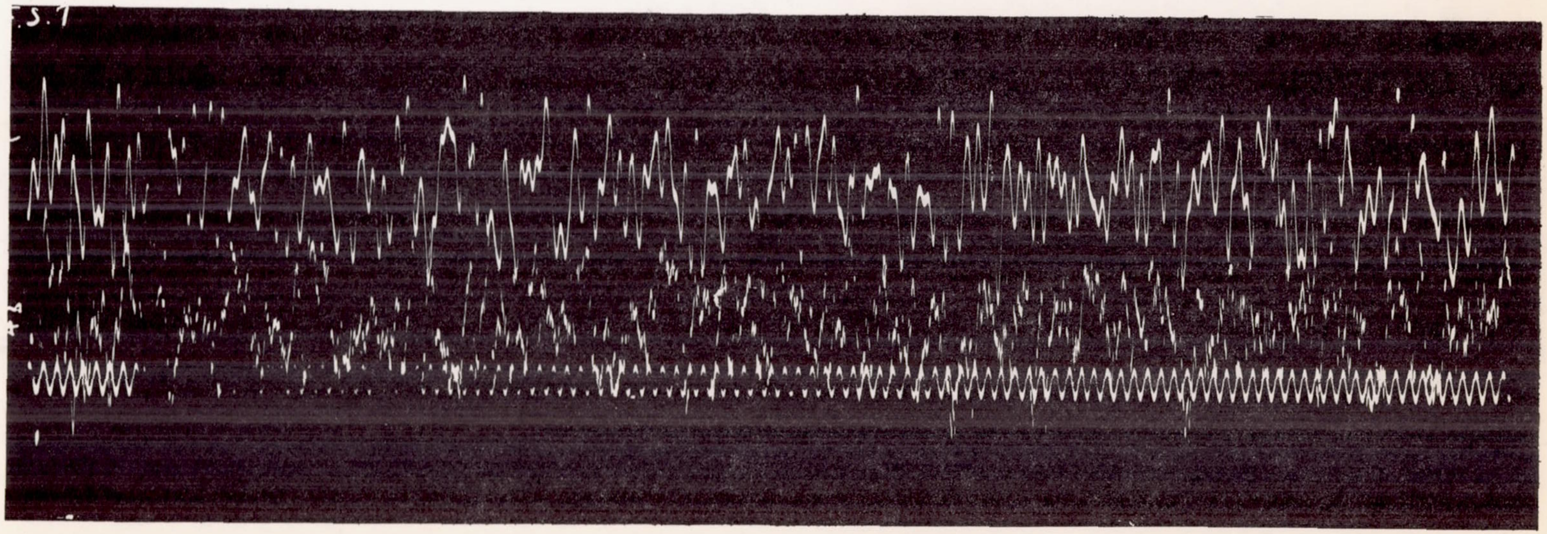


(a)

Fish tail
Attenuation, 5

Hot wire
Attenuation, 2

300-cycle timer



(b)

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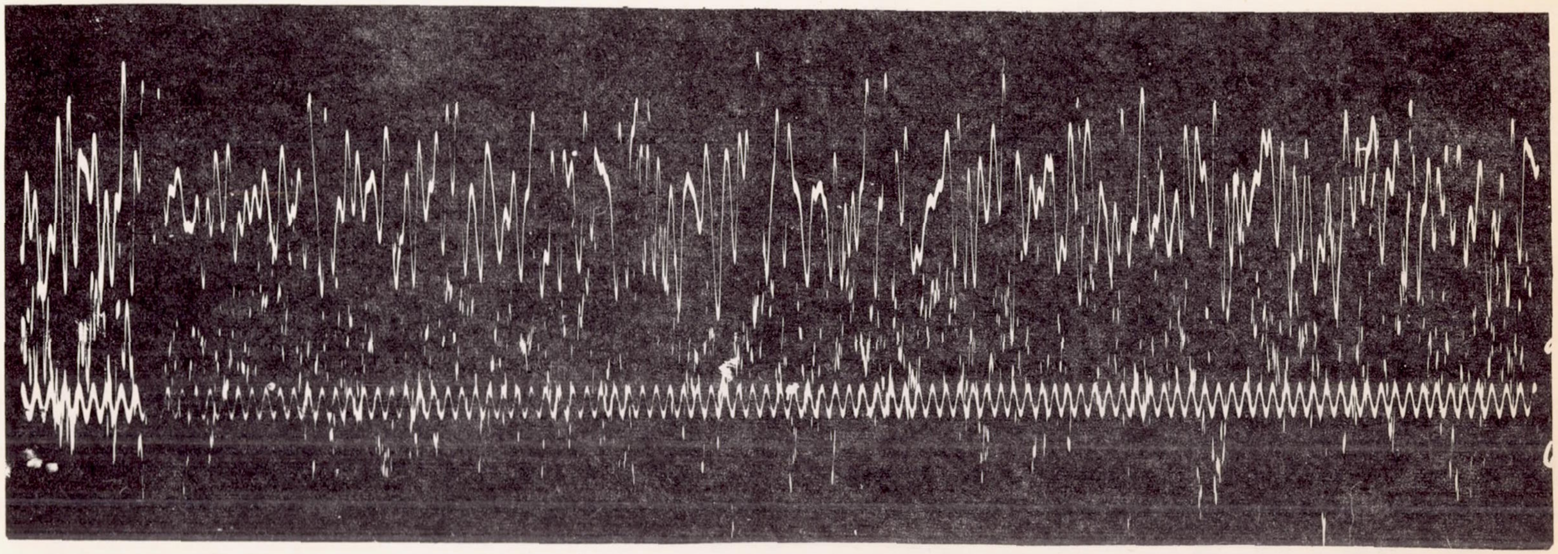
Airspeed, 85 mph; L, 0.7°; rudder deflection, 0°

Figure 1.

Fish tail
Attenuation, 5

Hot wire
Attenuation, 1

300-cycle timer



(c)

Airspeed, 85 mph; L, 0.7°; rudder deflection, 0°.

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Figure 1.- Concluded.

14.8 N

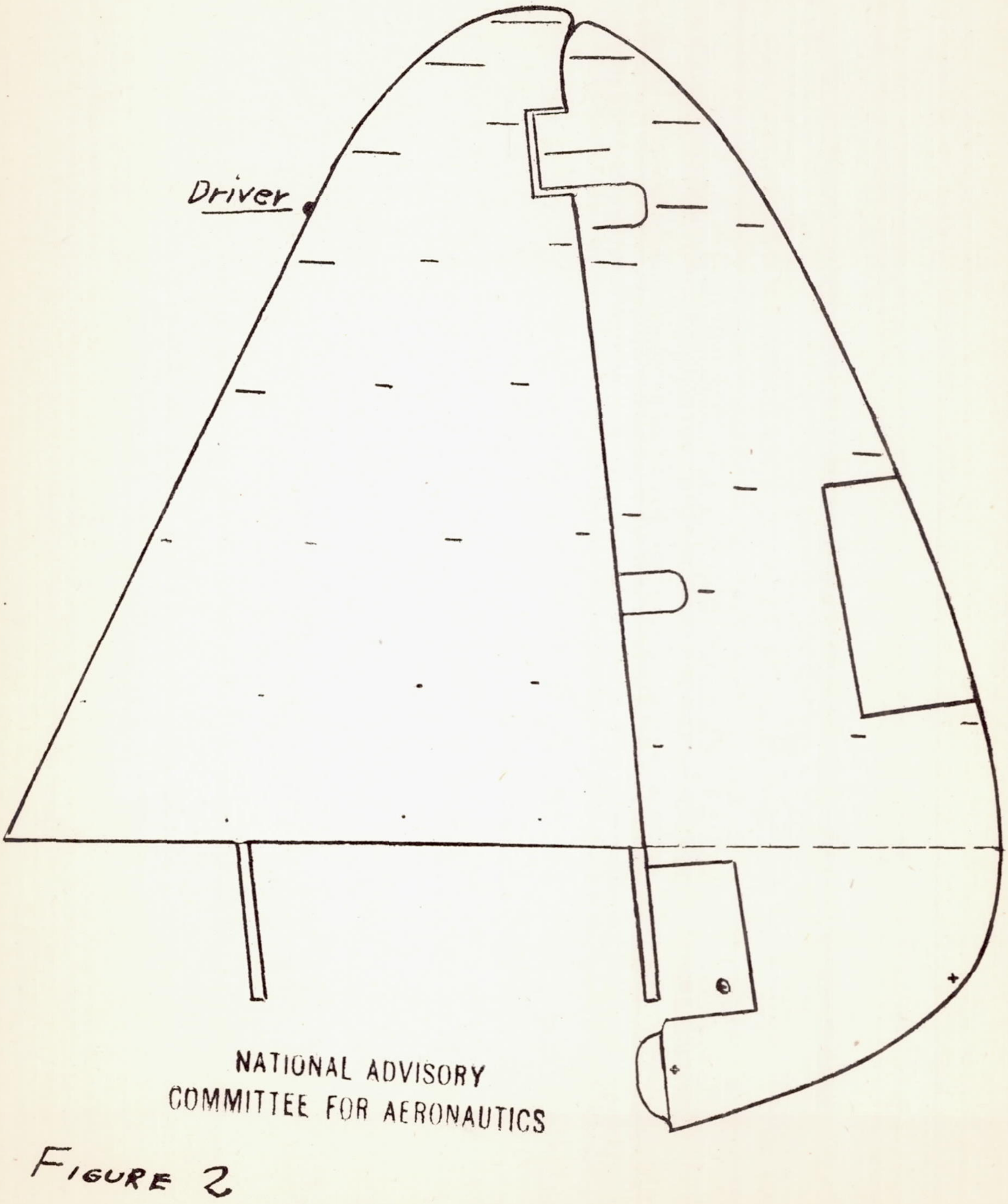

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FIGURE 2

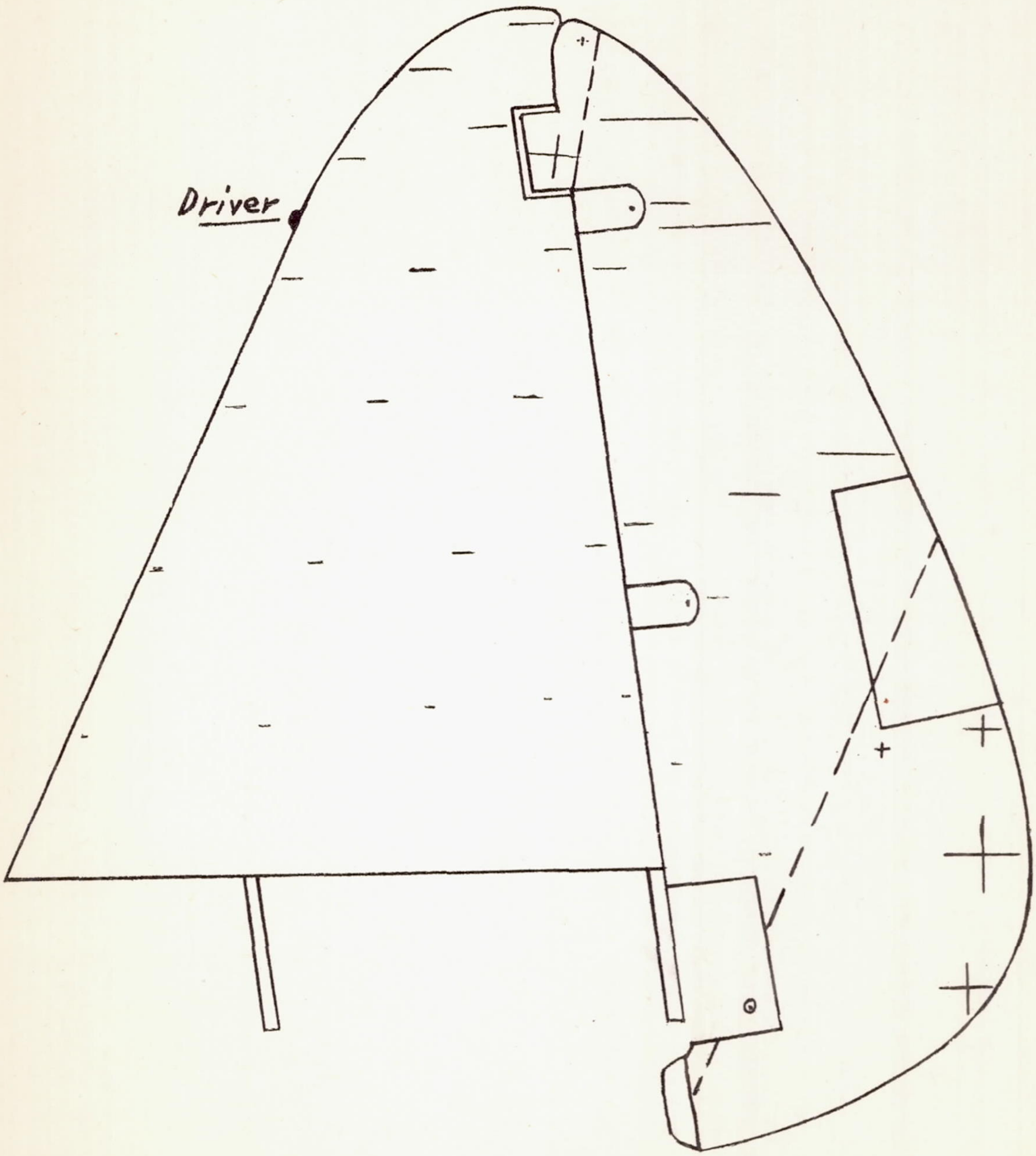

FIGURE 3. TAB LOCKED

53 ~

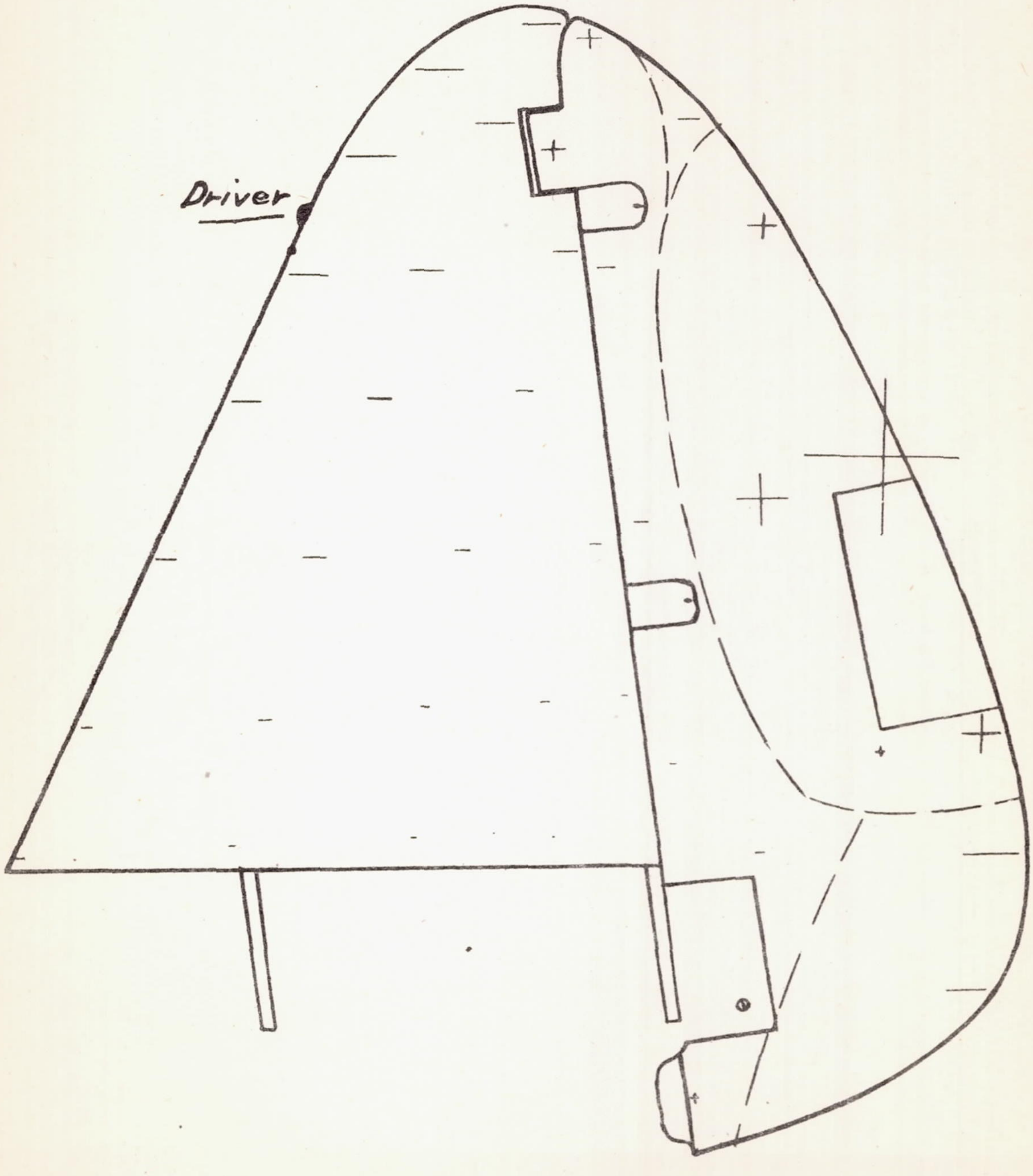

FIGURE 4. TAB LOCKED

75 ~

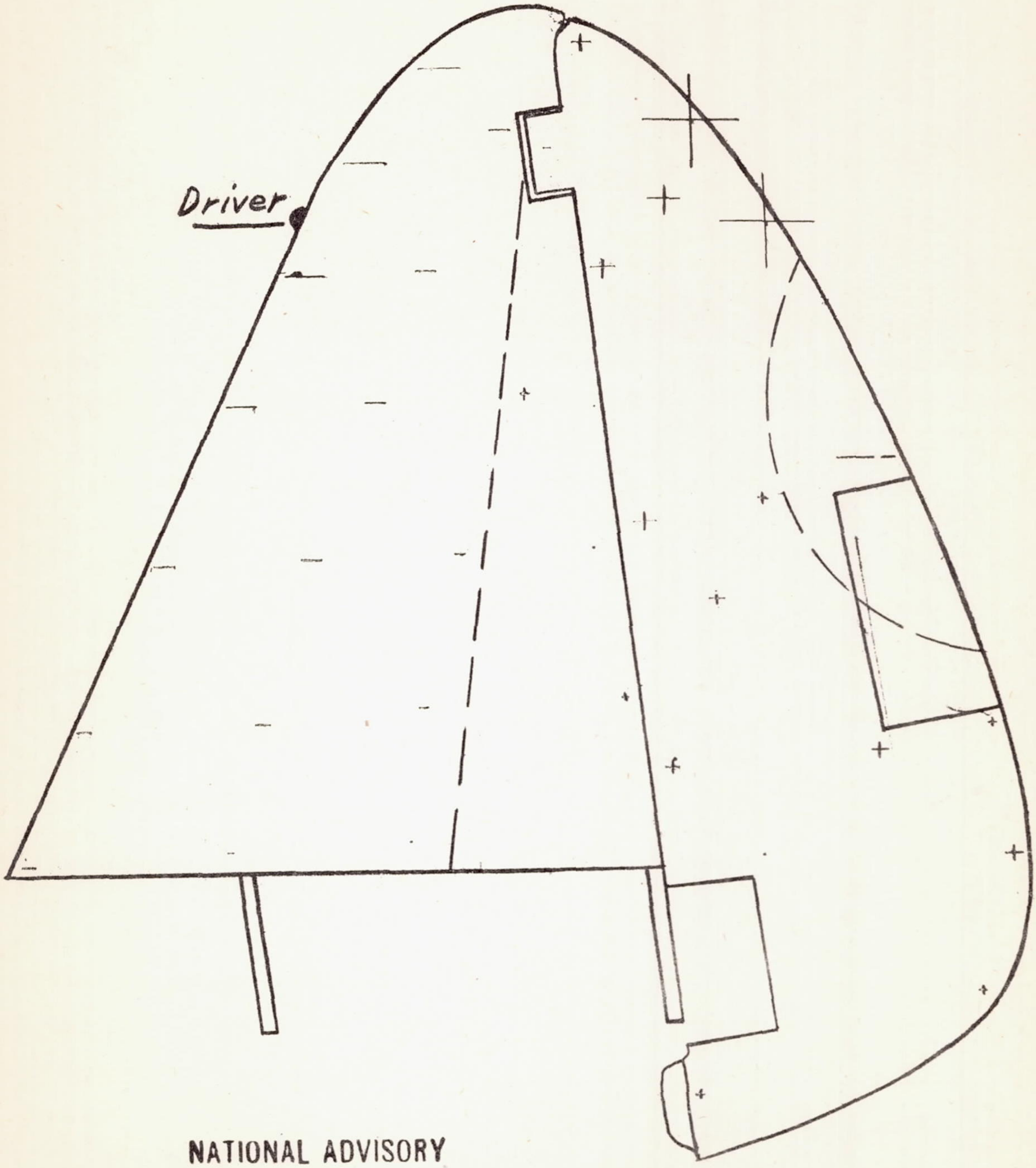

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FIGURE 5. TAB LOCKED

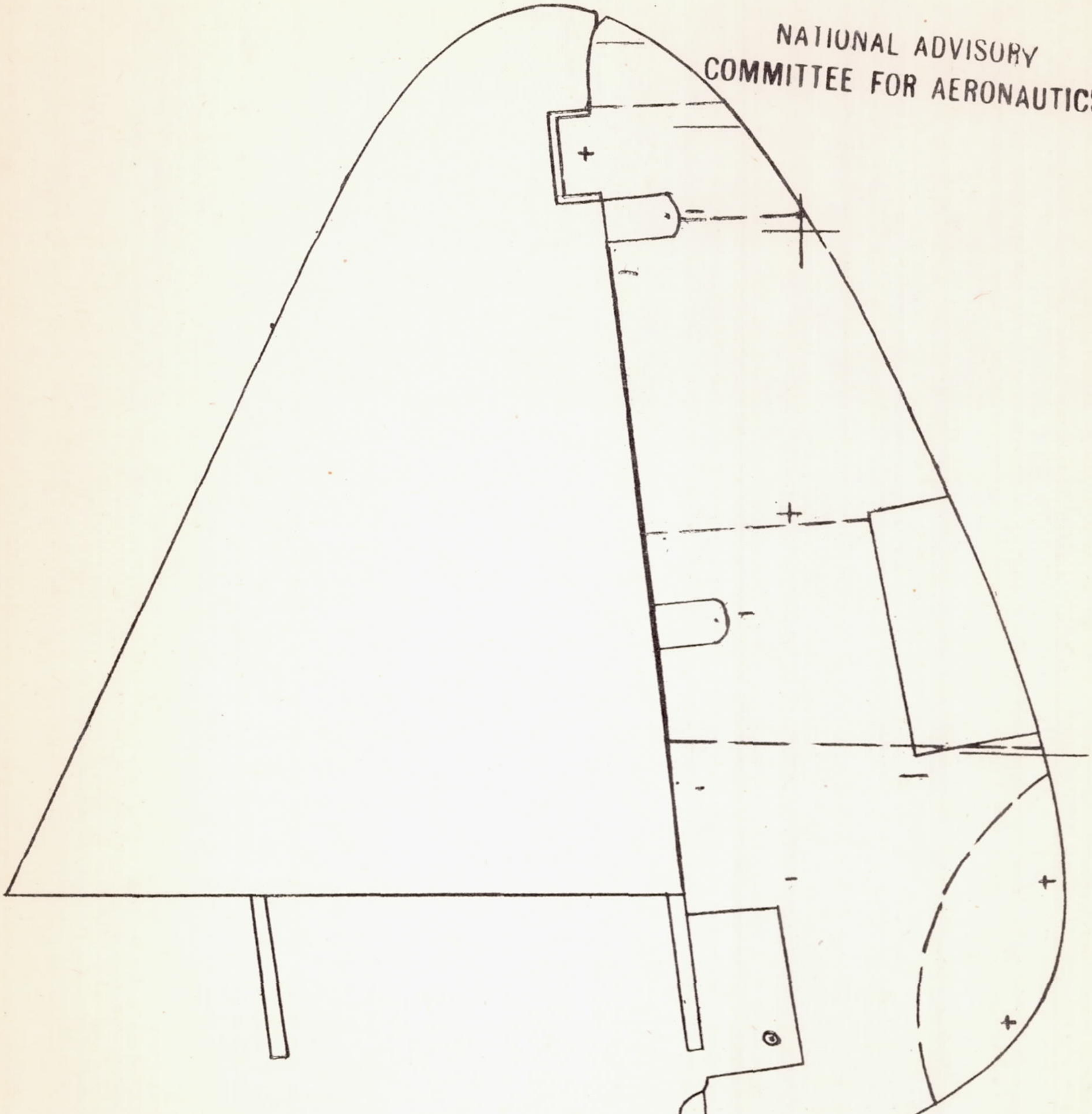


FIGURE 6. Tab Locked

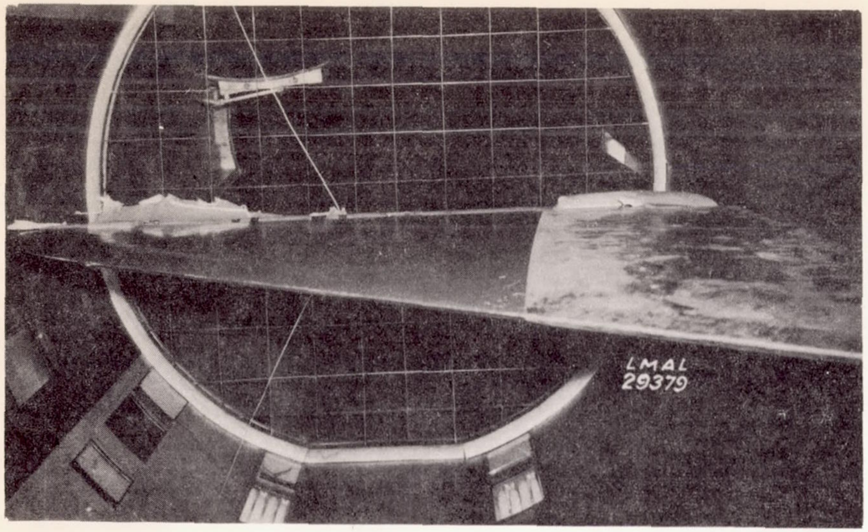


Figure 7.

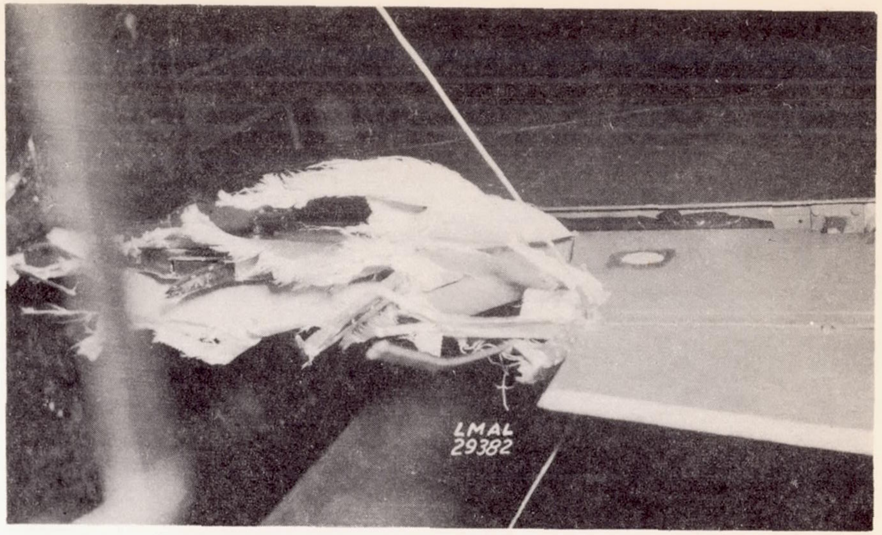


Figure 9.

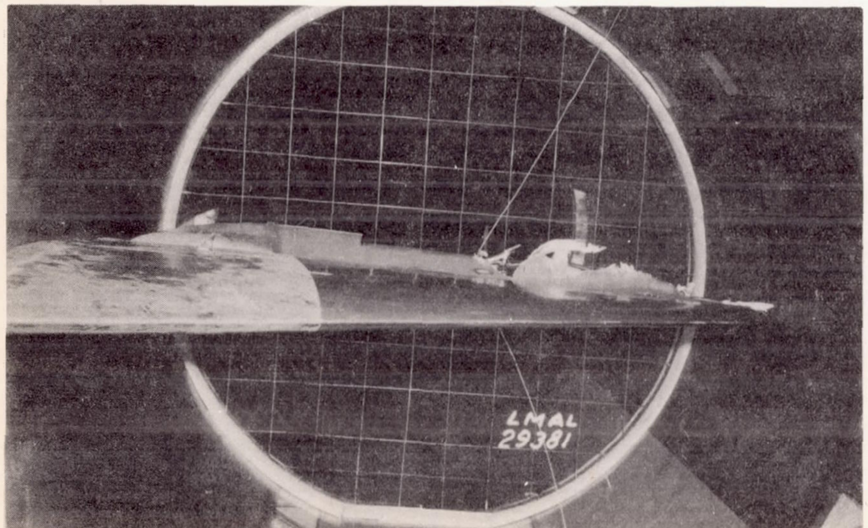


Figure 8.

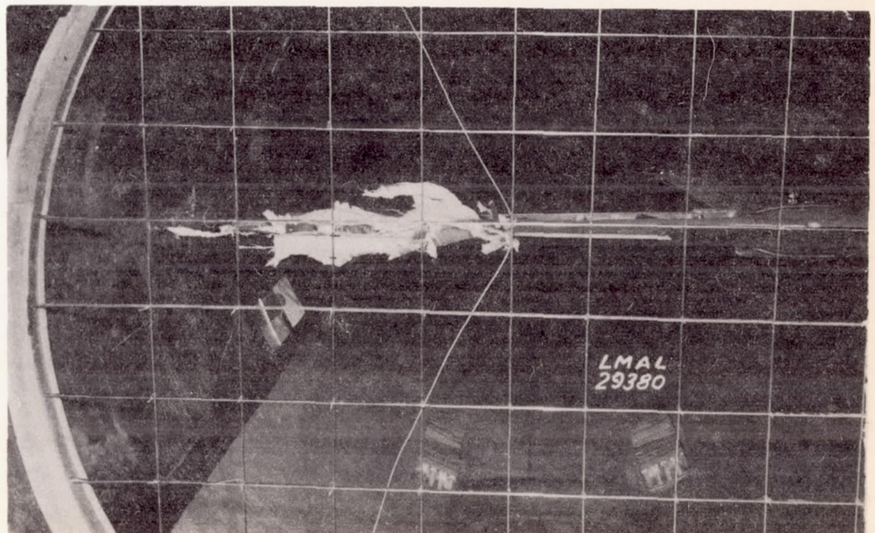


Figure 10.

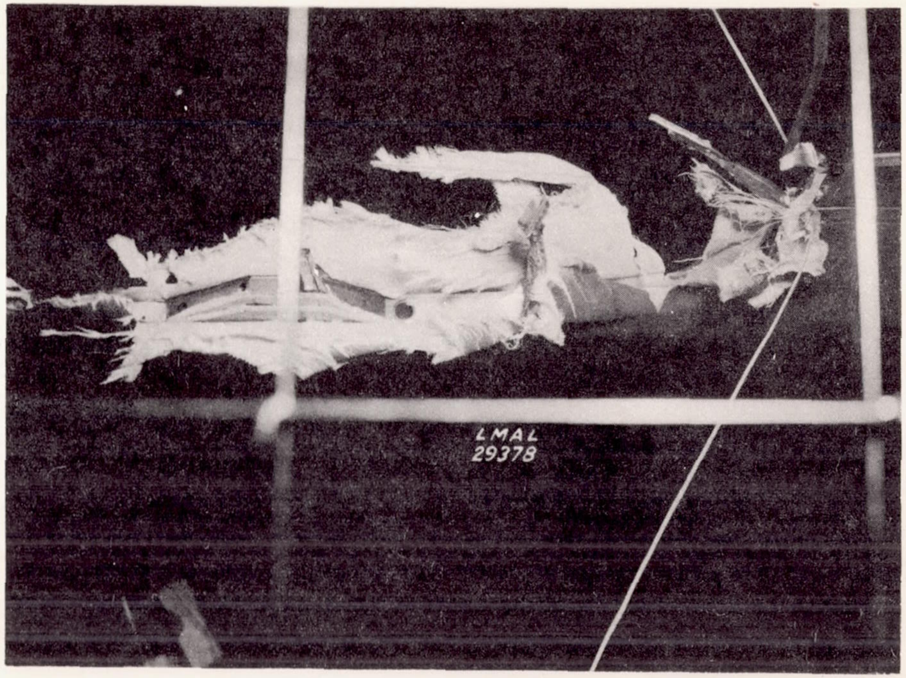


Figure 11.

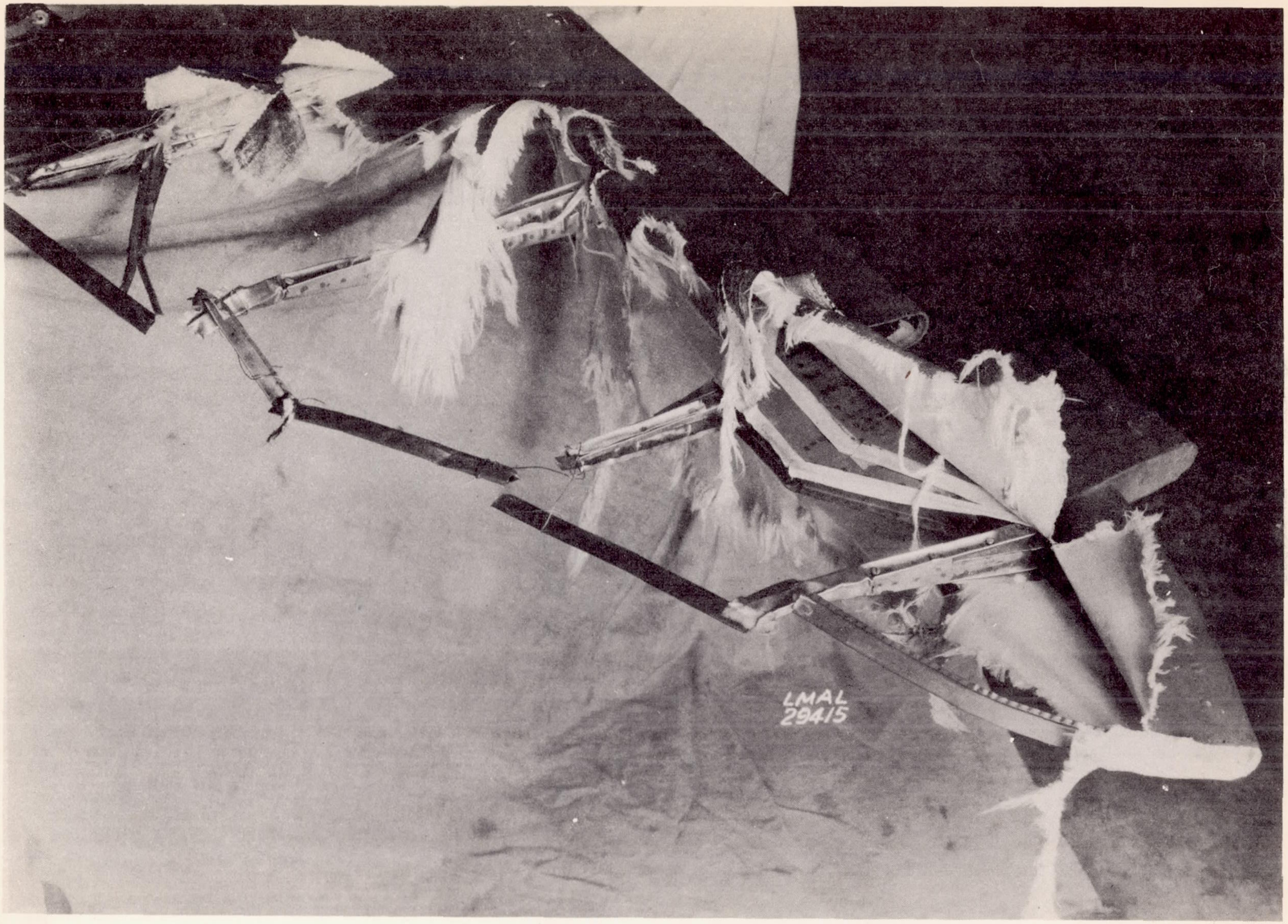
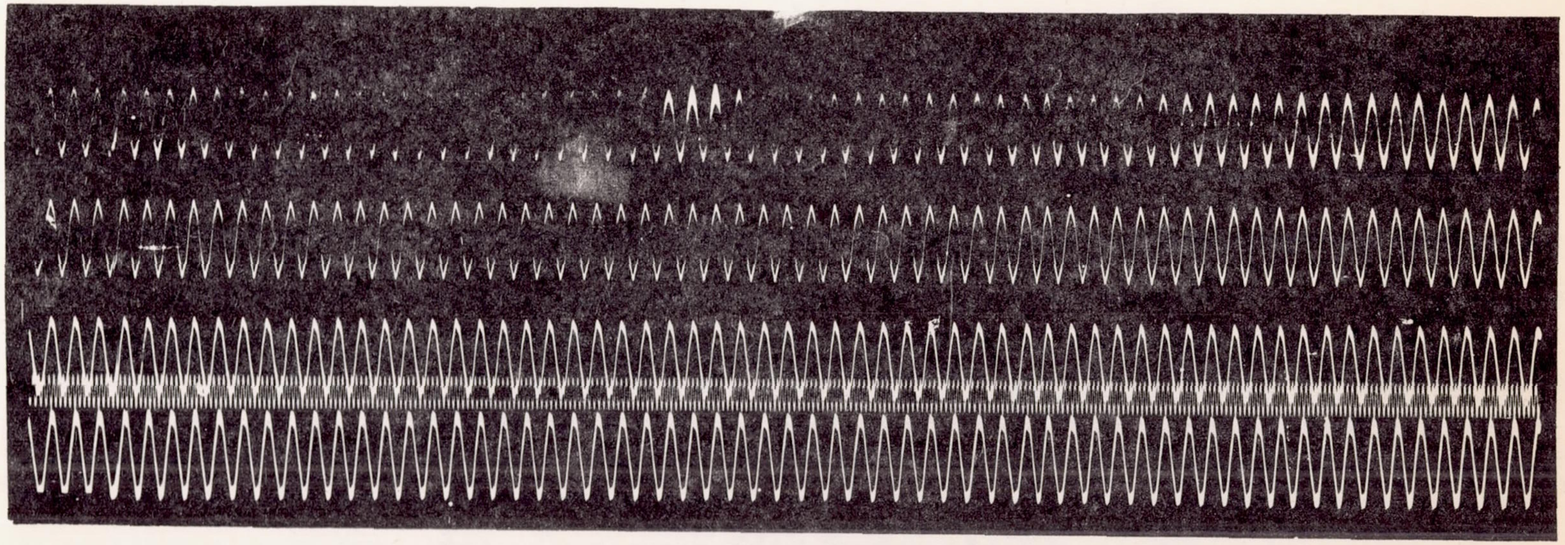


Figure 12.

60-cycle calibration
Attenuation, 100



(a) Calibration of equipment.

Figure 13.

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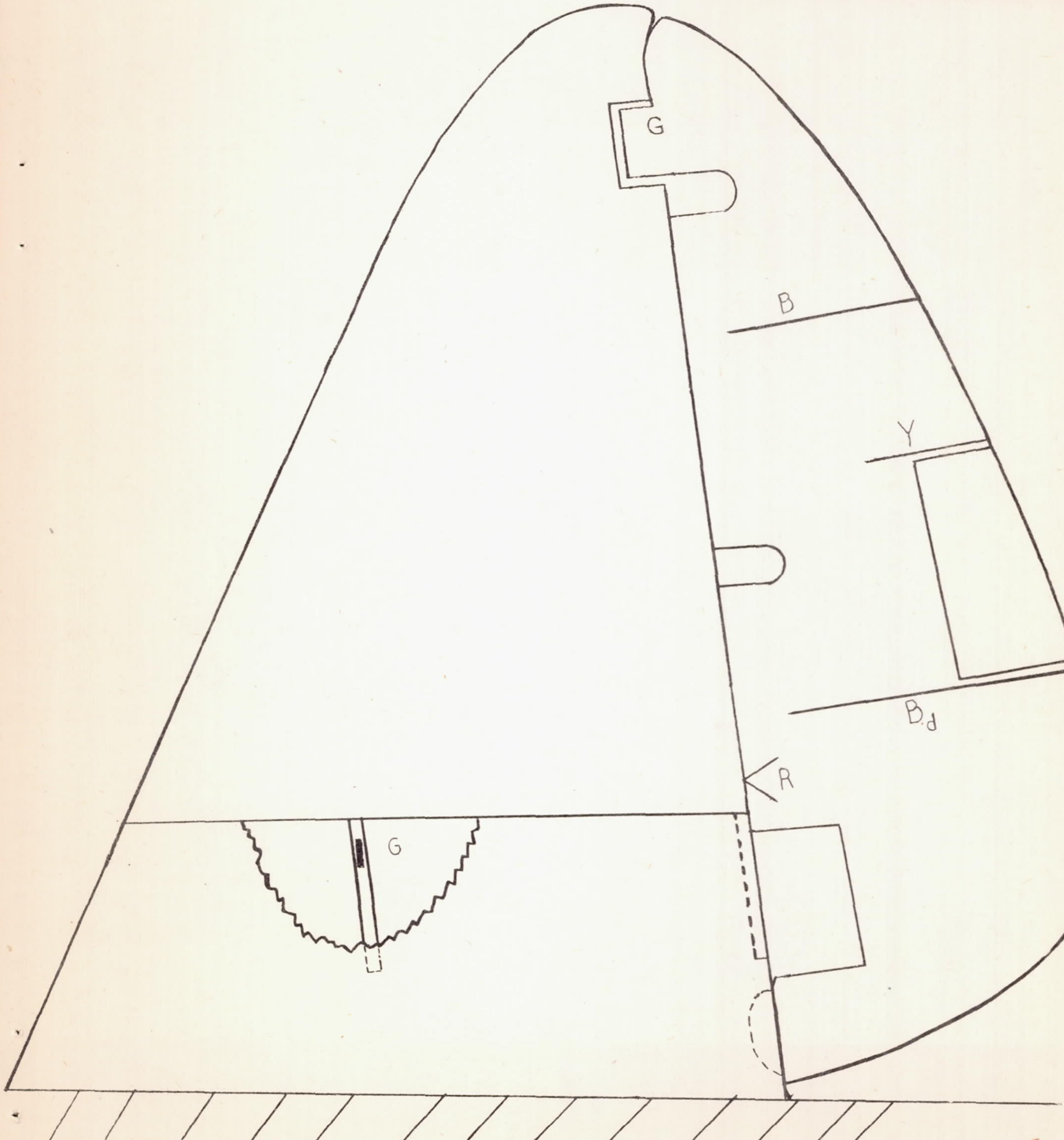
(b) Location of strain gages.

Figure 13.- Continued.



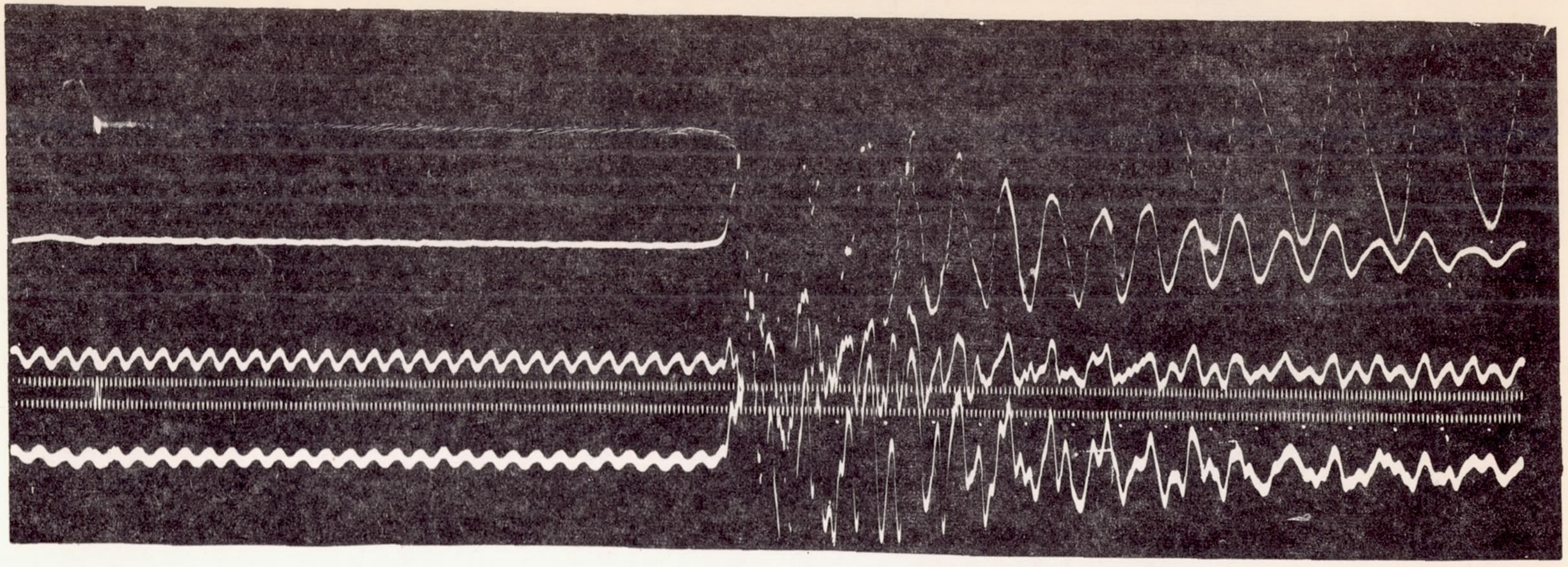
Attenuation

1 G

2 R

1 Y

1 B up



(c)

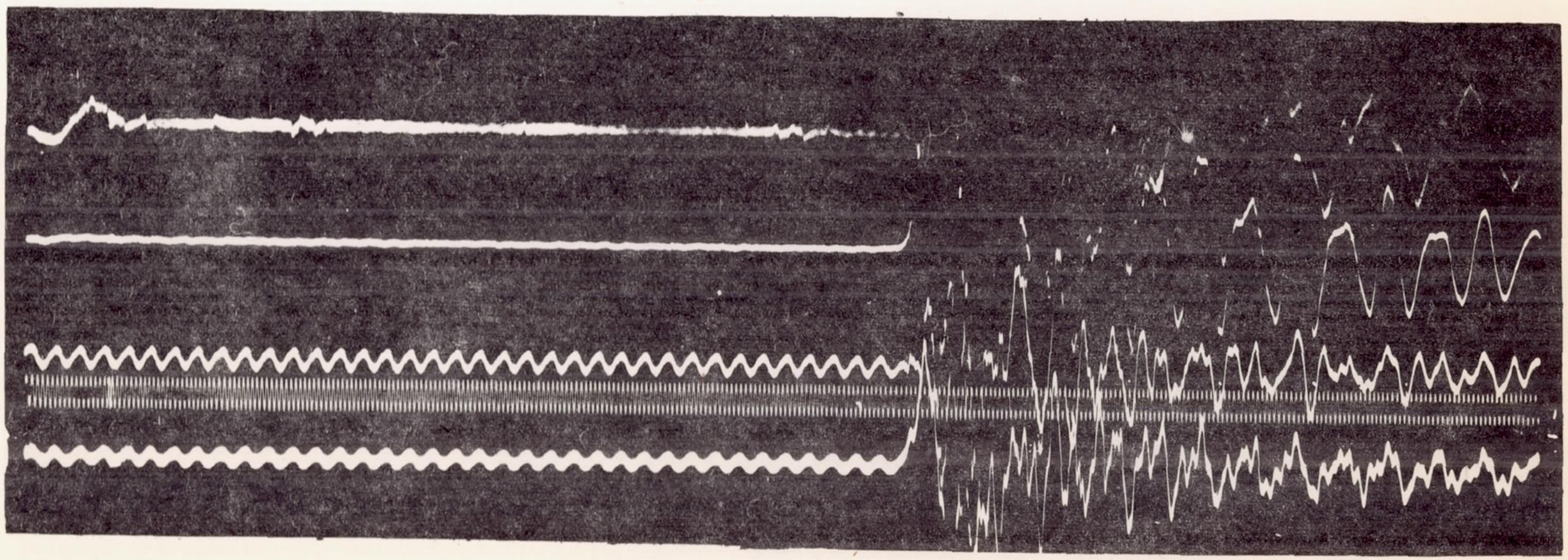
Attenuation

1 G

2 R

1 Y

1 B down



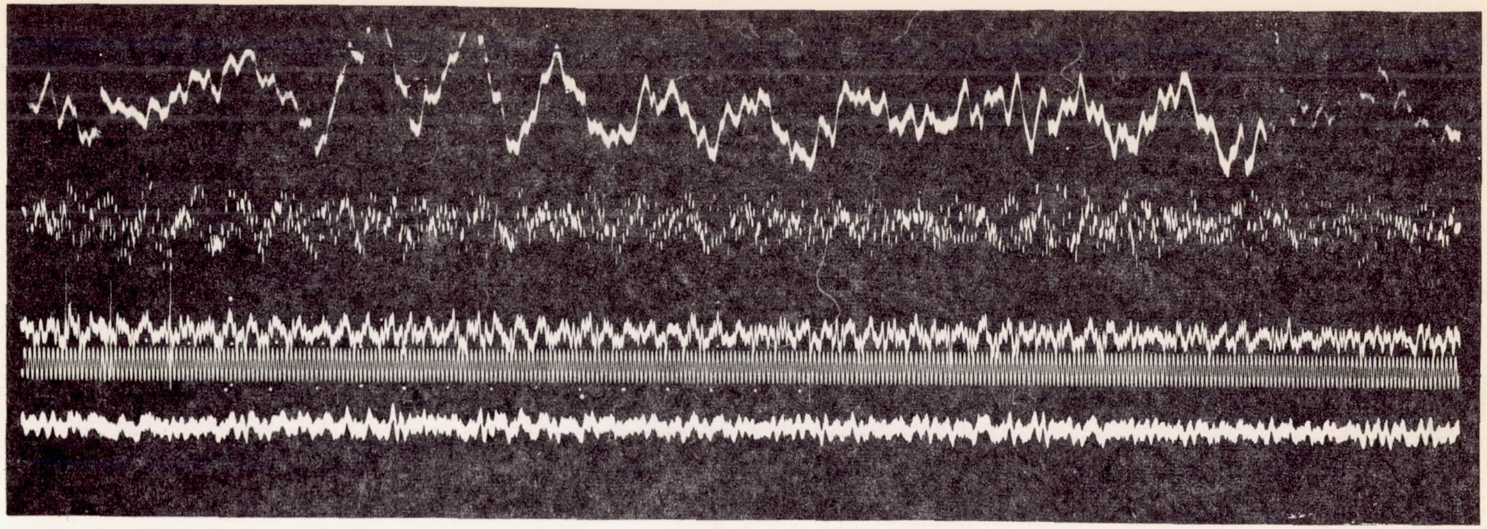
(d)

Rudder jerked; airspeed, 0.

Figure 13.- Concluded.

Attenuation

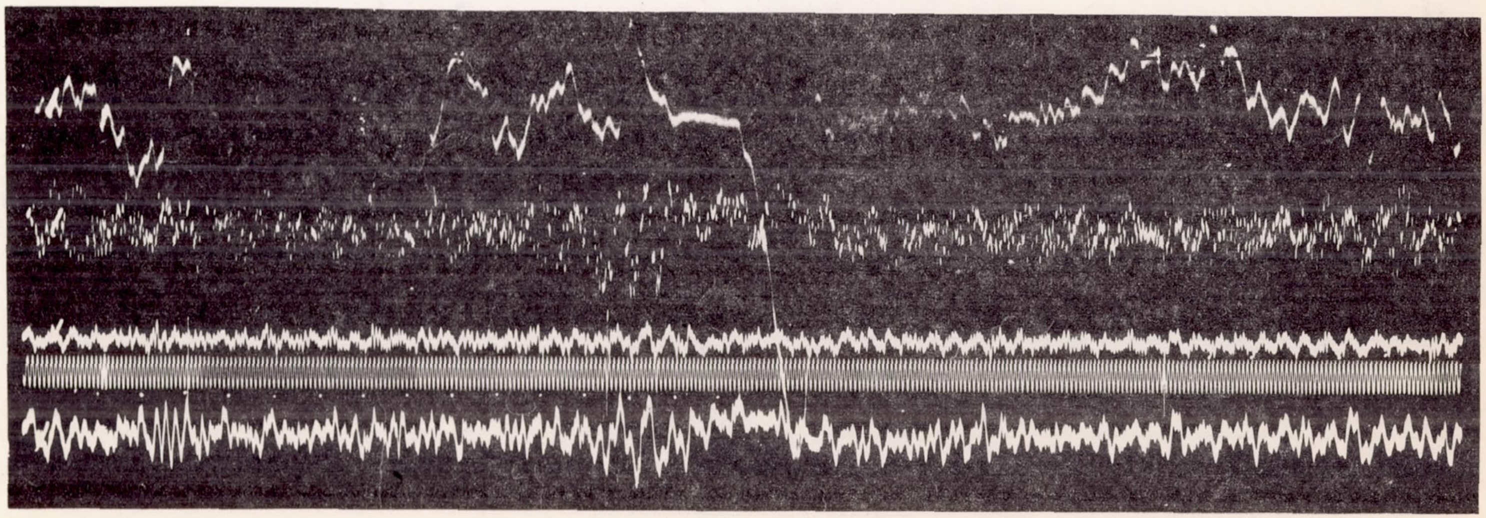
1	G
1	R
1	Y
1	B up



(a)

Attenuation

1	G
1	R
1	Y
1	B up



(b)

Airspeed, 200 mph.

Figure 14.

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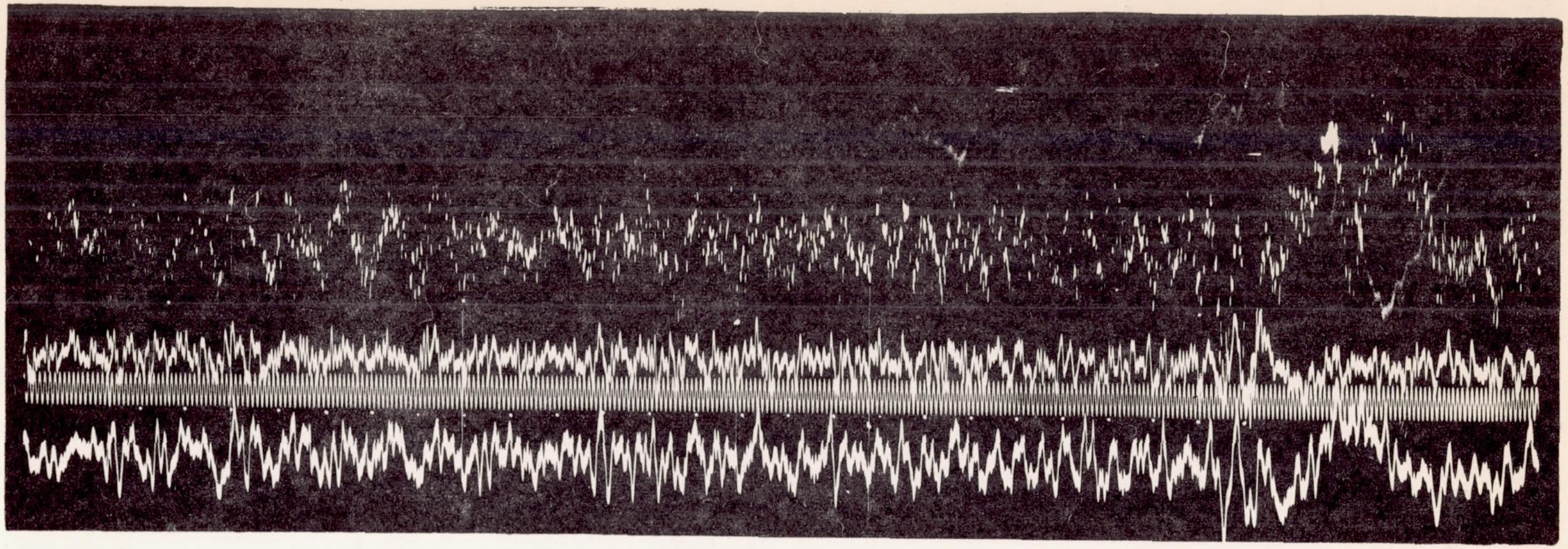
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 300 mph.

Figure 15.

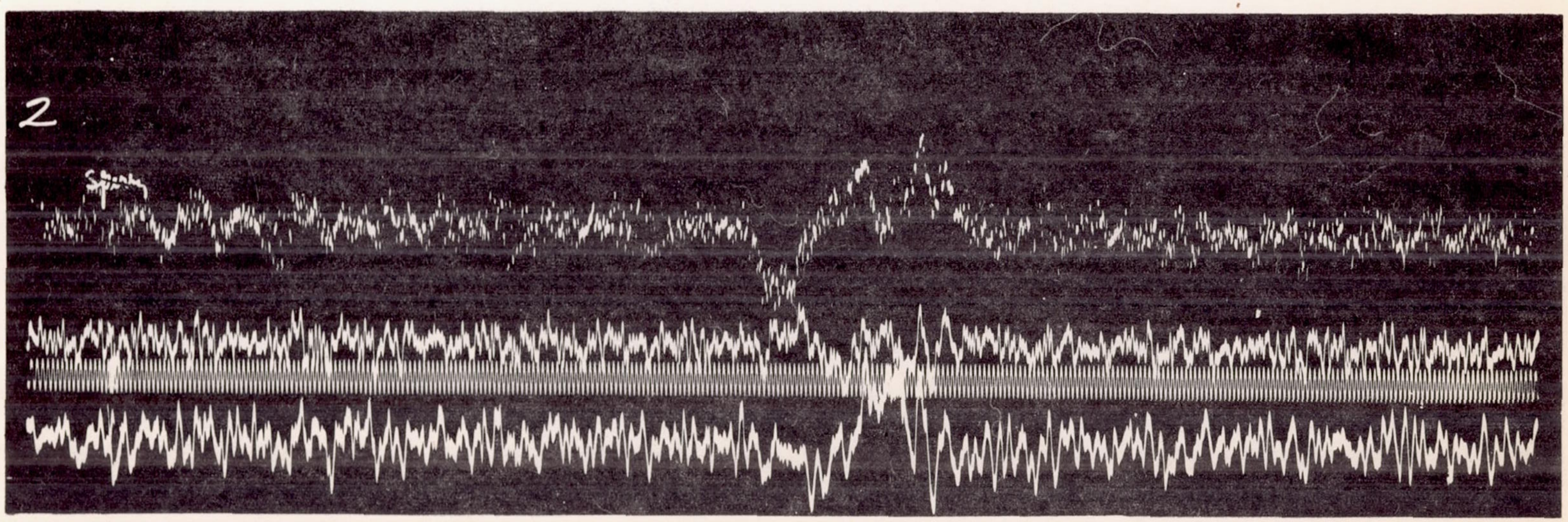
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 300 mph.

Figure 16.

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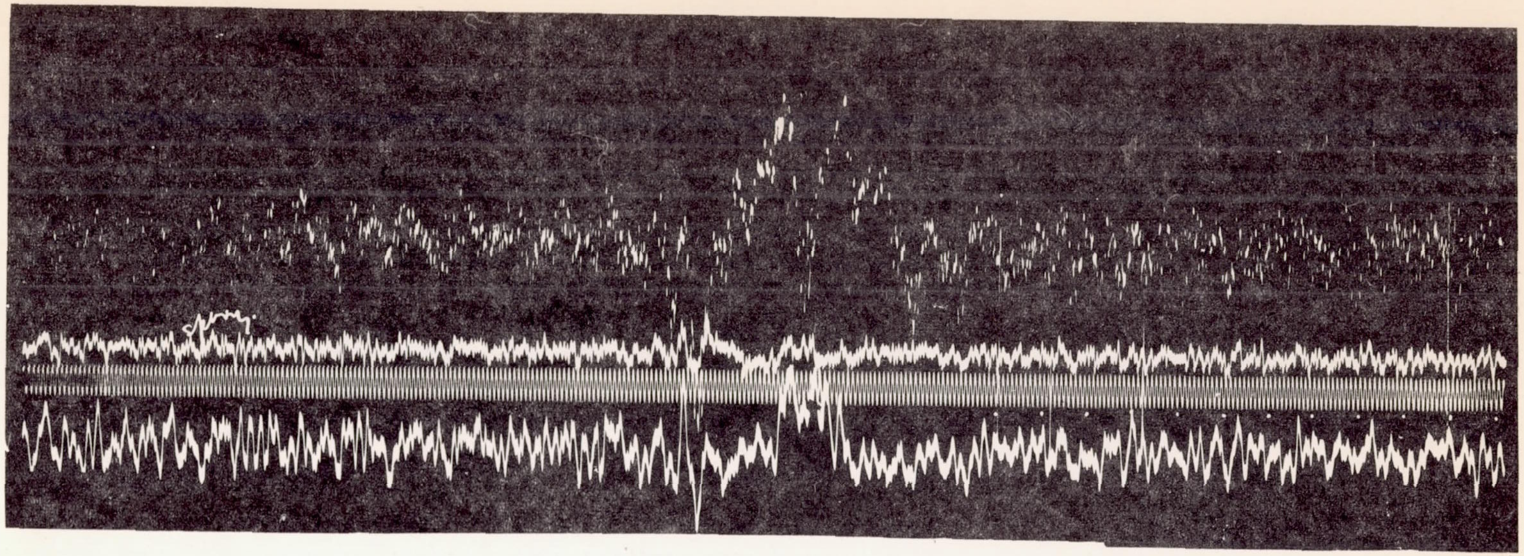
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 300 mph.

Figure 17.

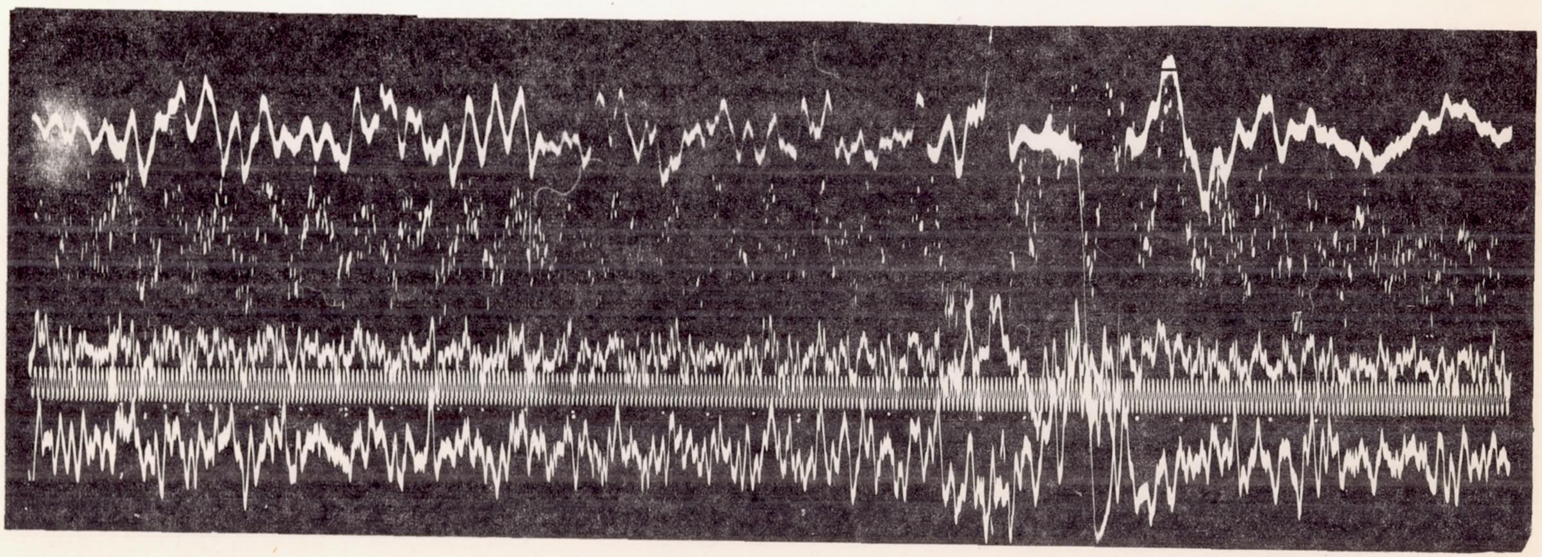
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 350 mph.

Figure 18.

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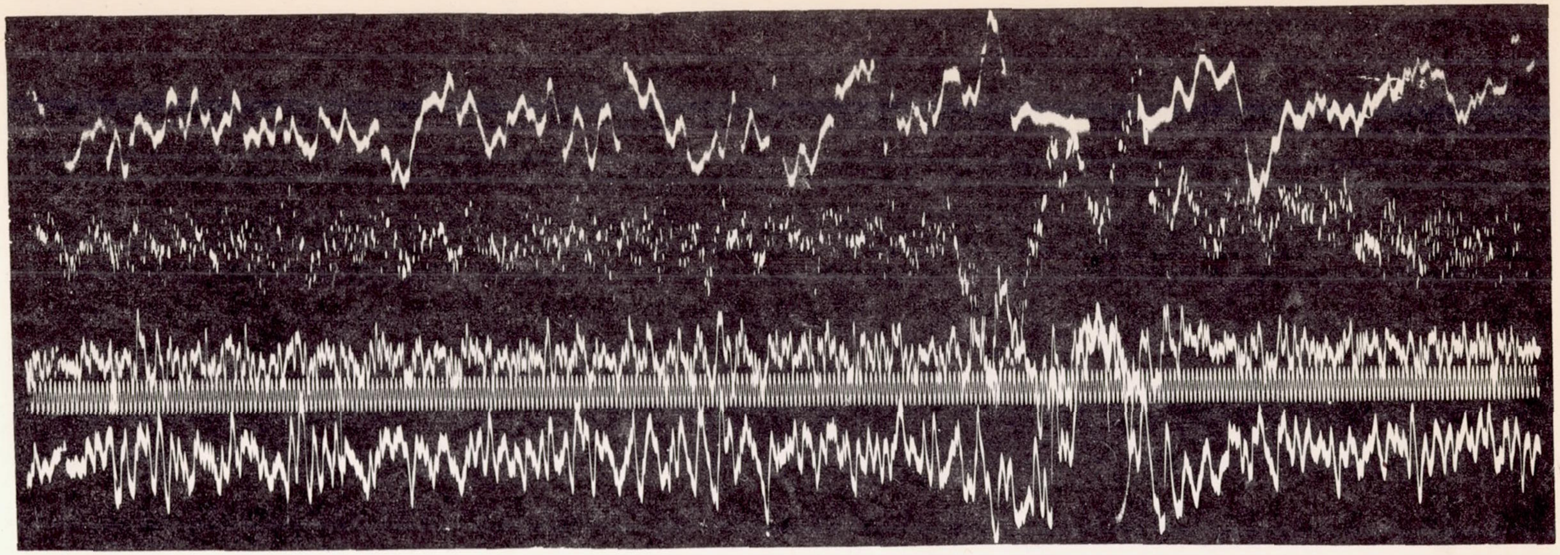
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 350 mph.

Figure 19.

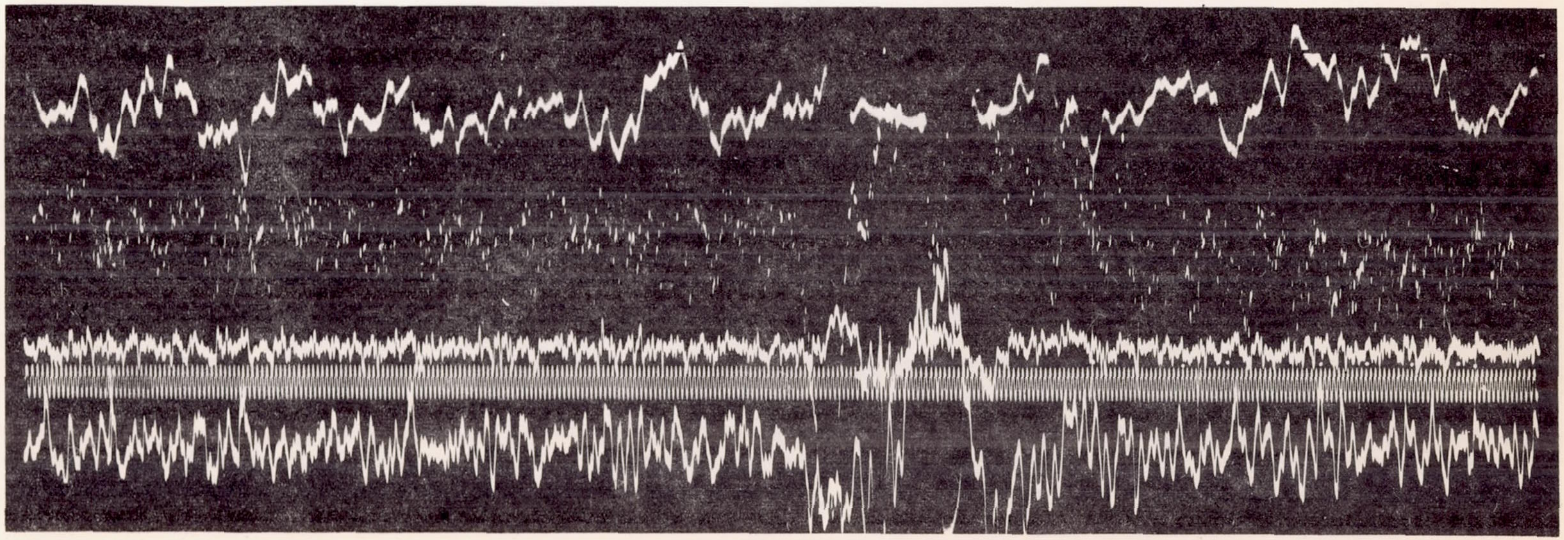
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 350 mph.

Figure 20.

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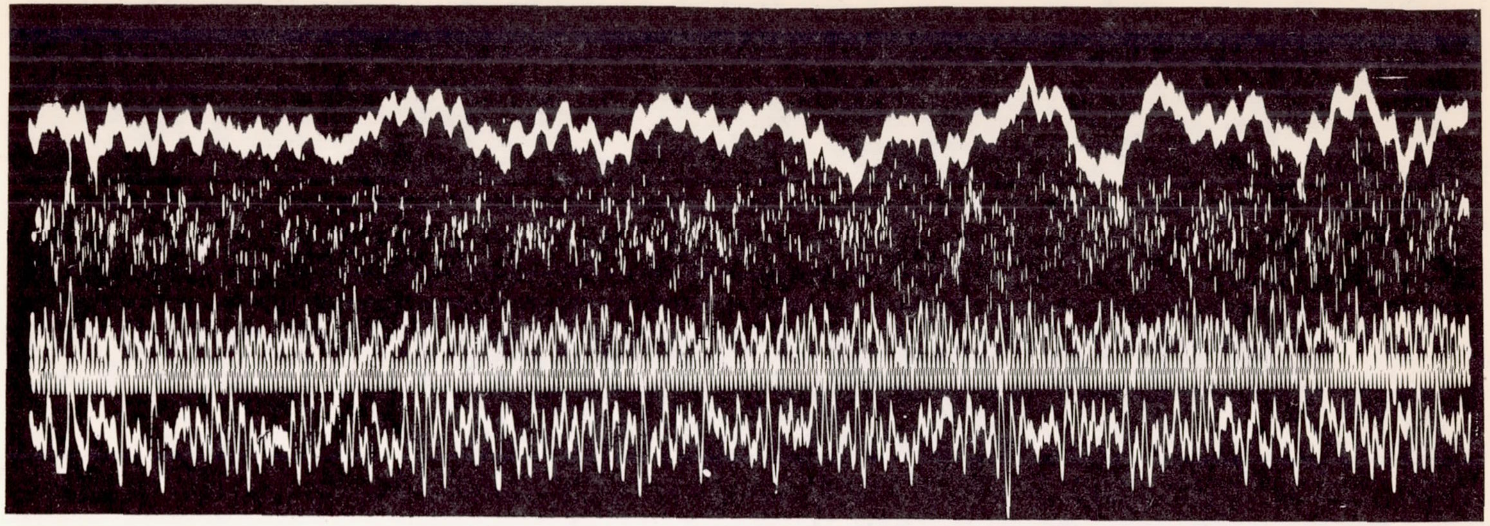
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 21.

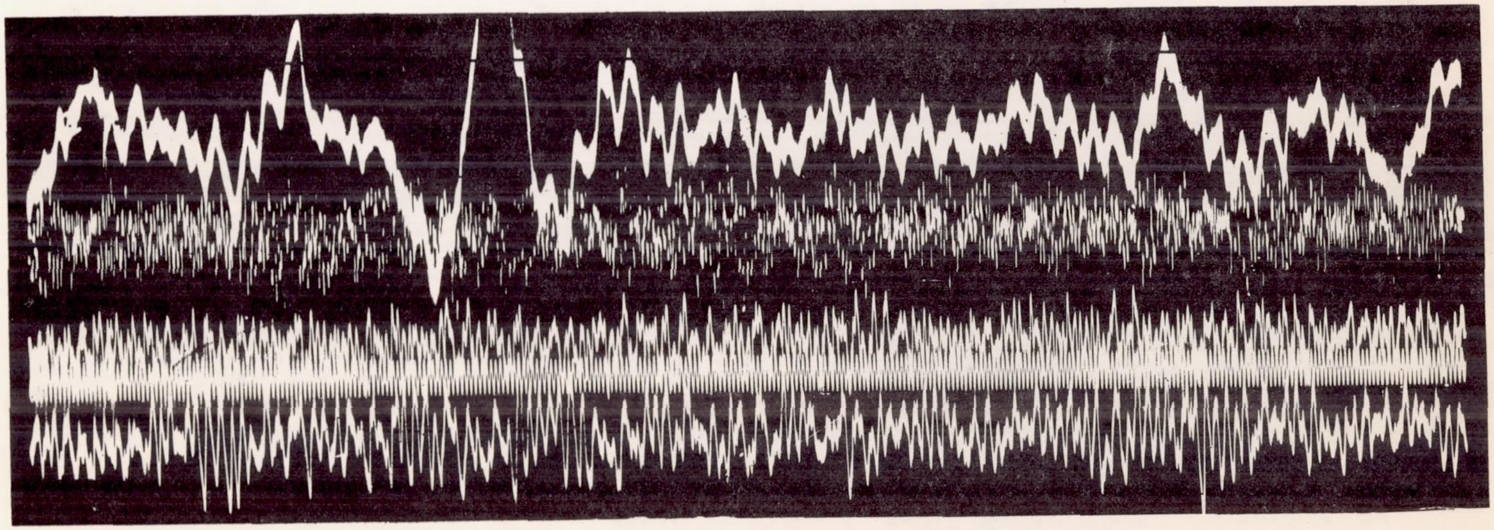
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 22.

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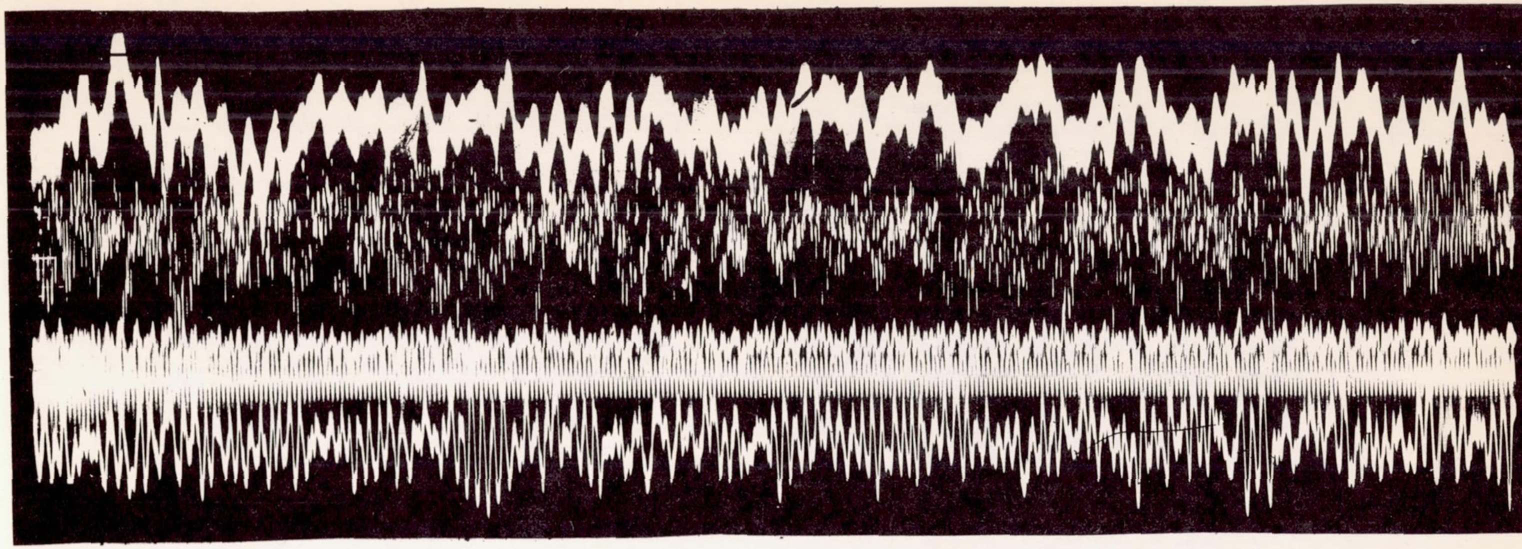
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 23.

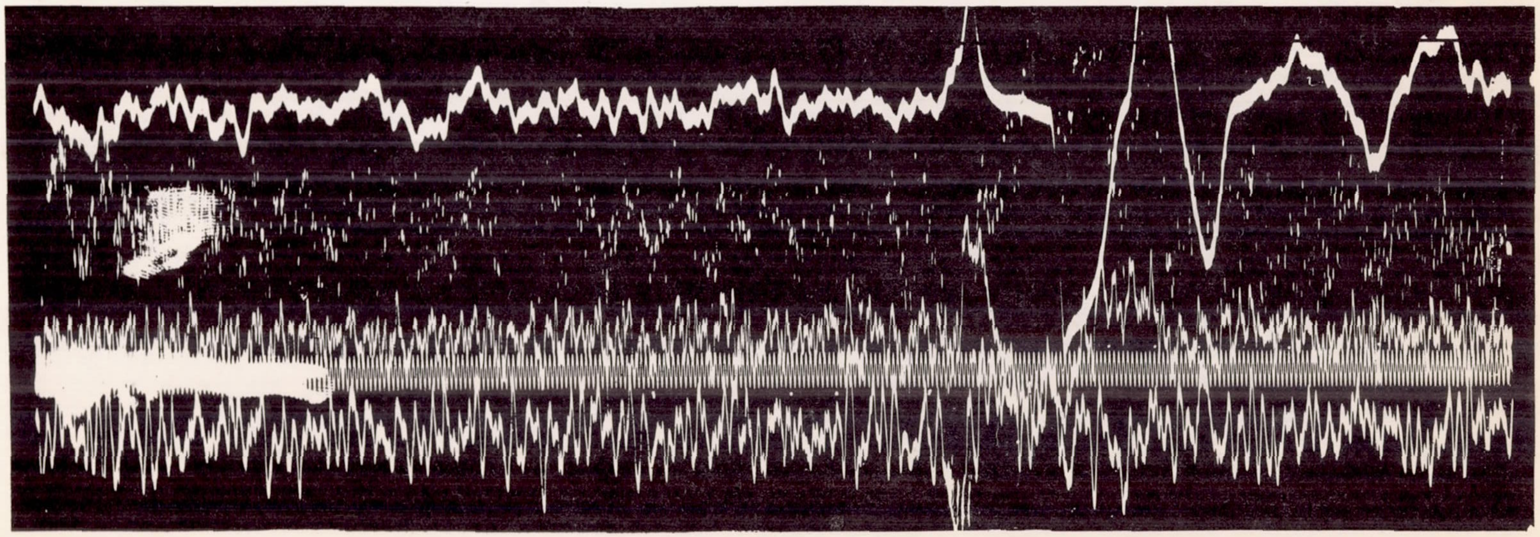
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 24.

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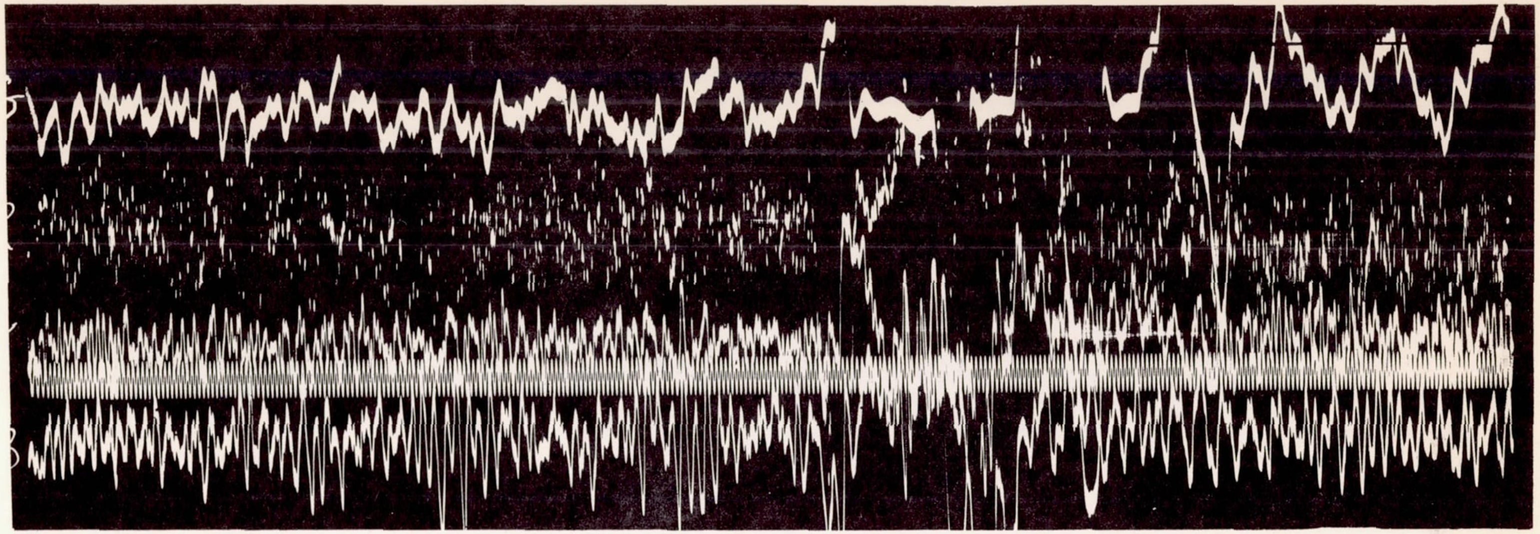
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 25.

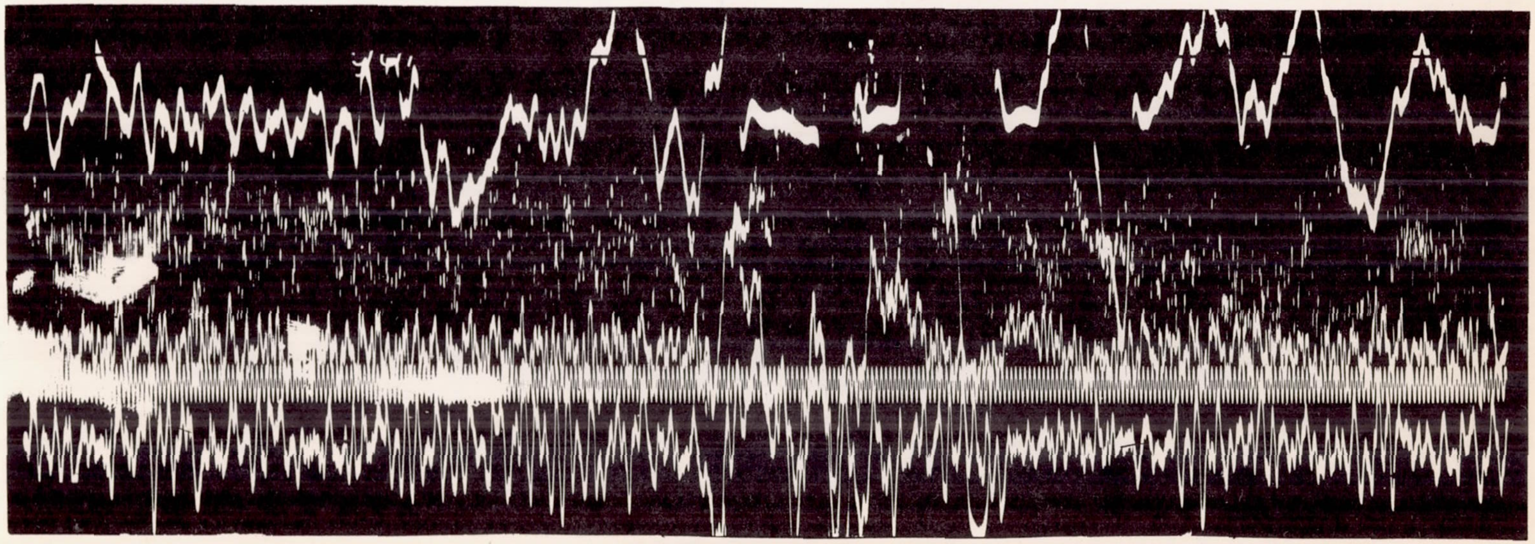
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 400 mph.

Figure 26.

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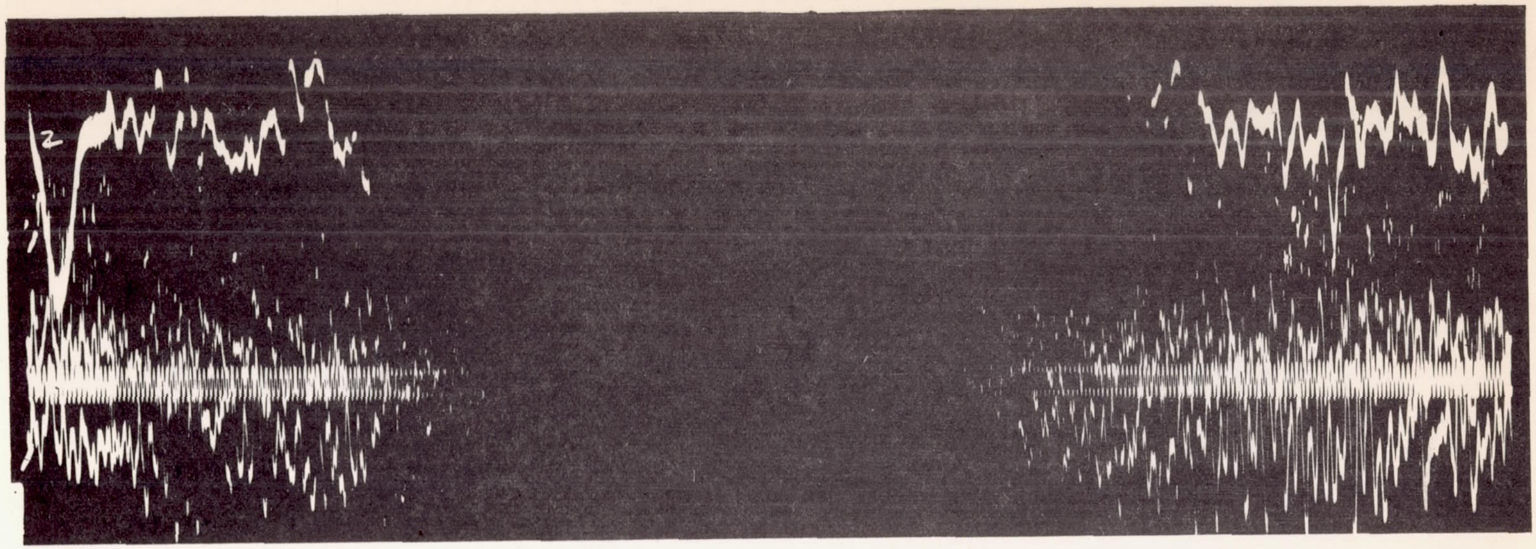
Attenuation

2 G

1 R

1 Y

1 B



Airspeed, 420 mph.

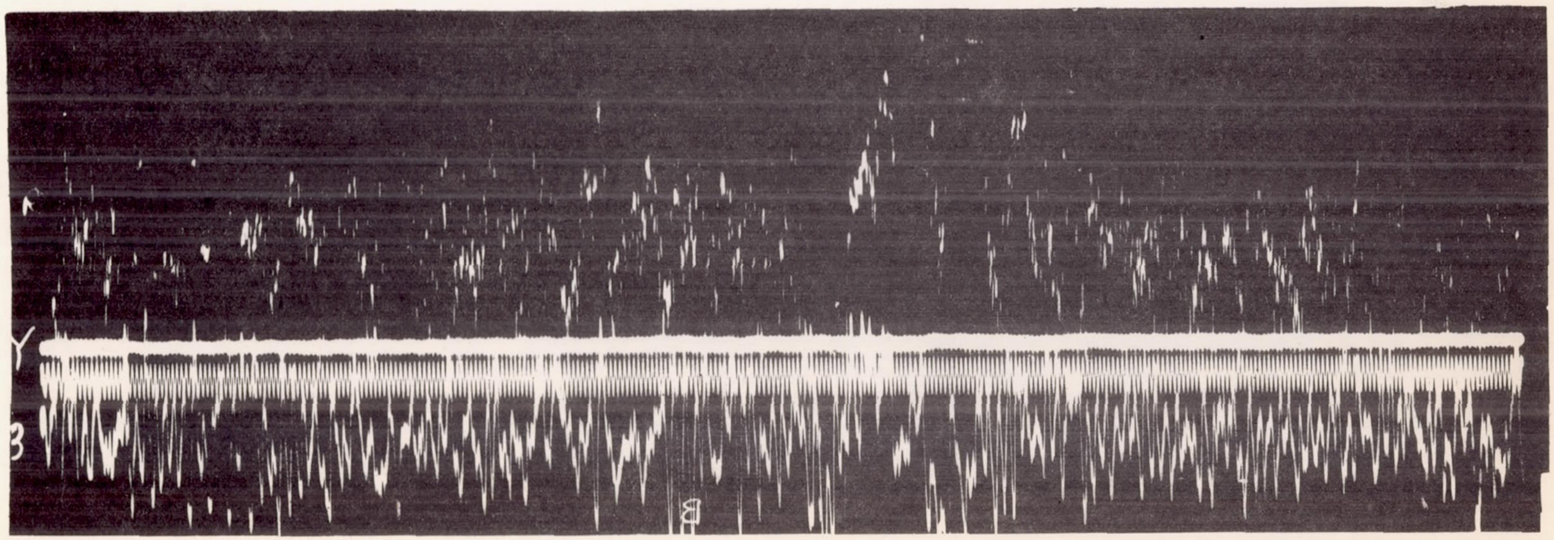
Figure 27.

Attenuation

1 R

1 Y

1 B



Airspeed, 440 mph.

Figure 28.

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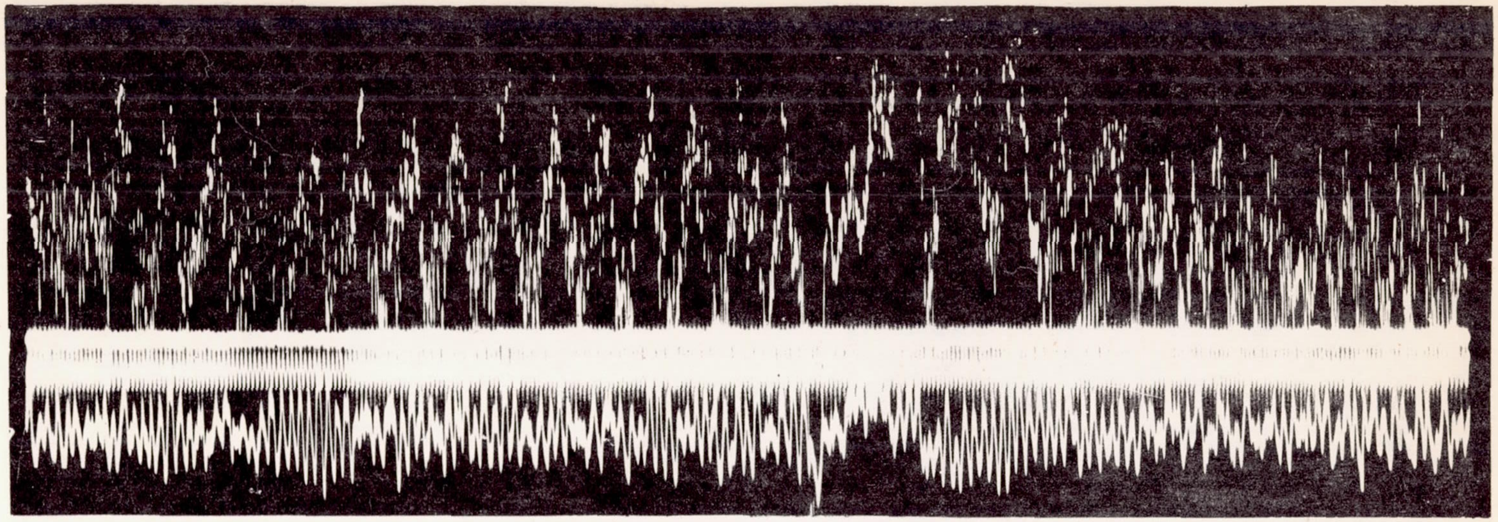
Attenuation

1 R

1 Y

1 B



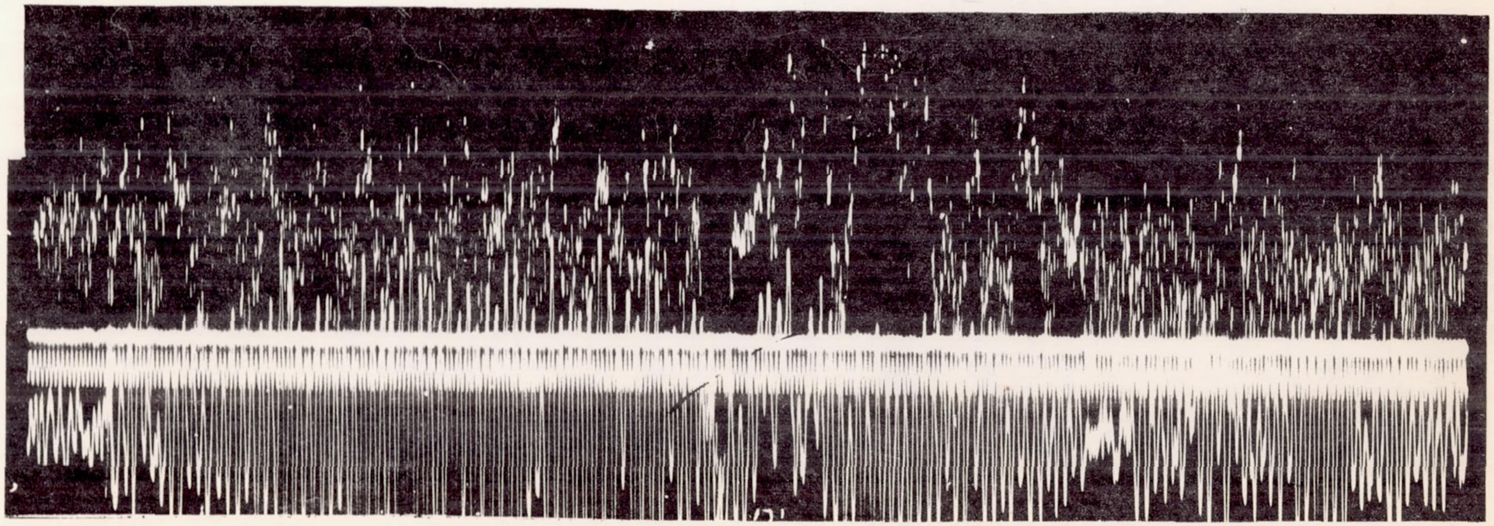
Airspeed near top speed (approx. 468 mph).

Figure 29.

Attenuation

1 R

1 B



Airspeed near top speed (approx. 468 mph).

Figure 30.

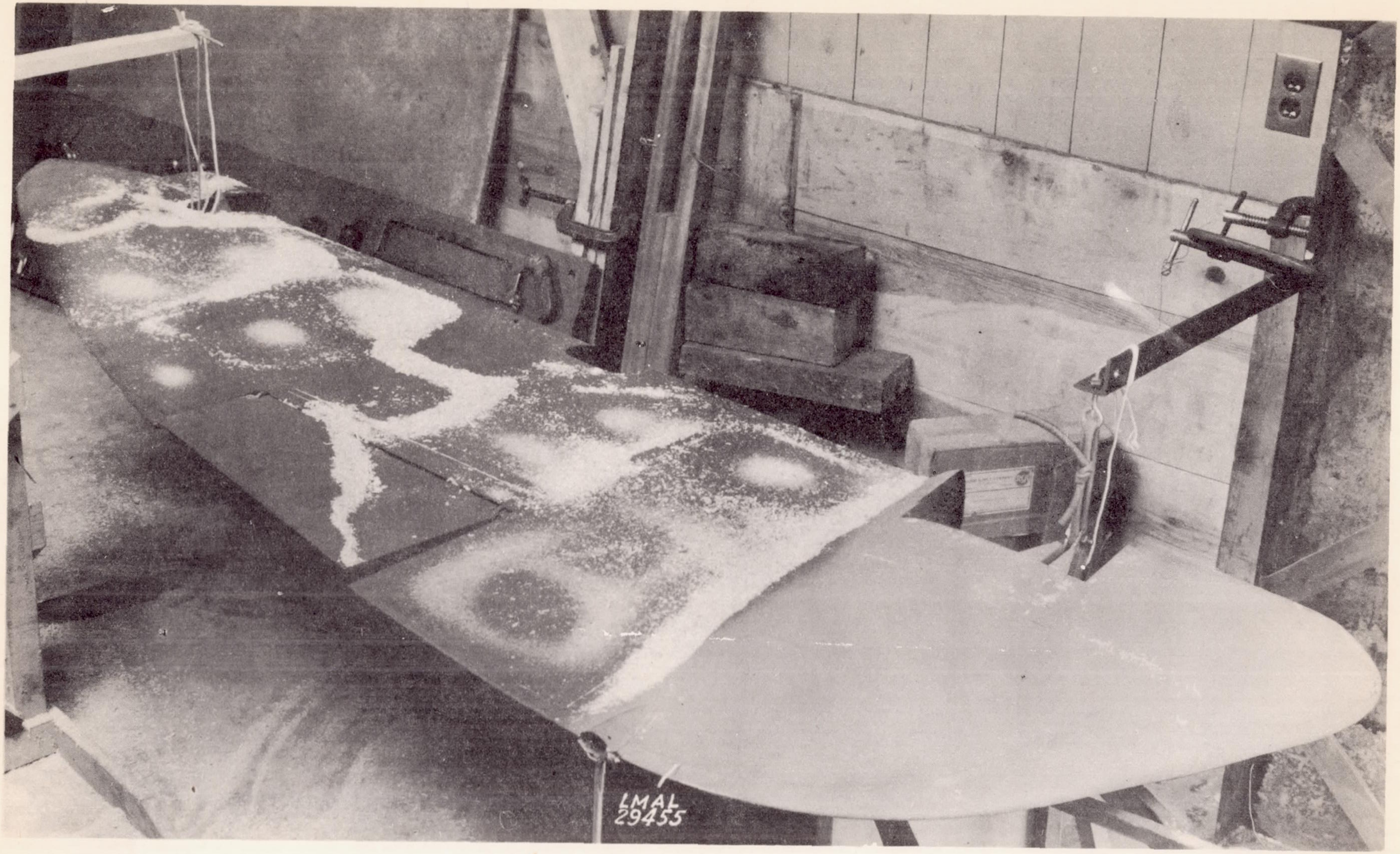


Figure 31.

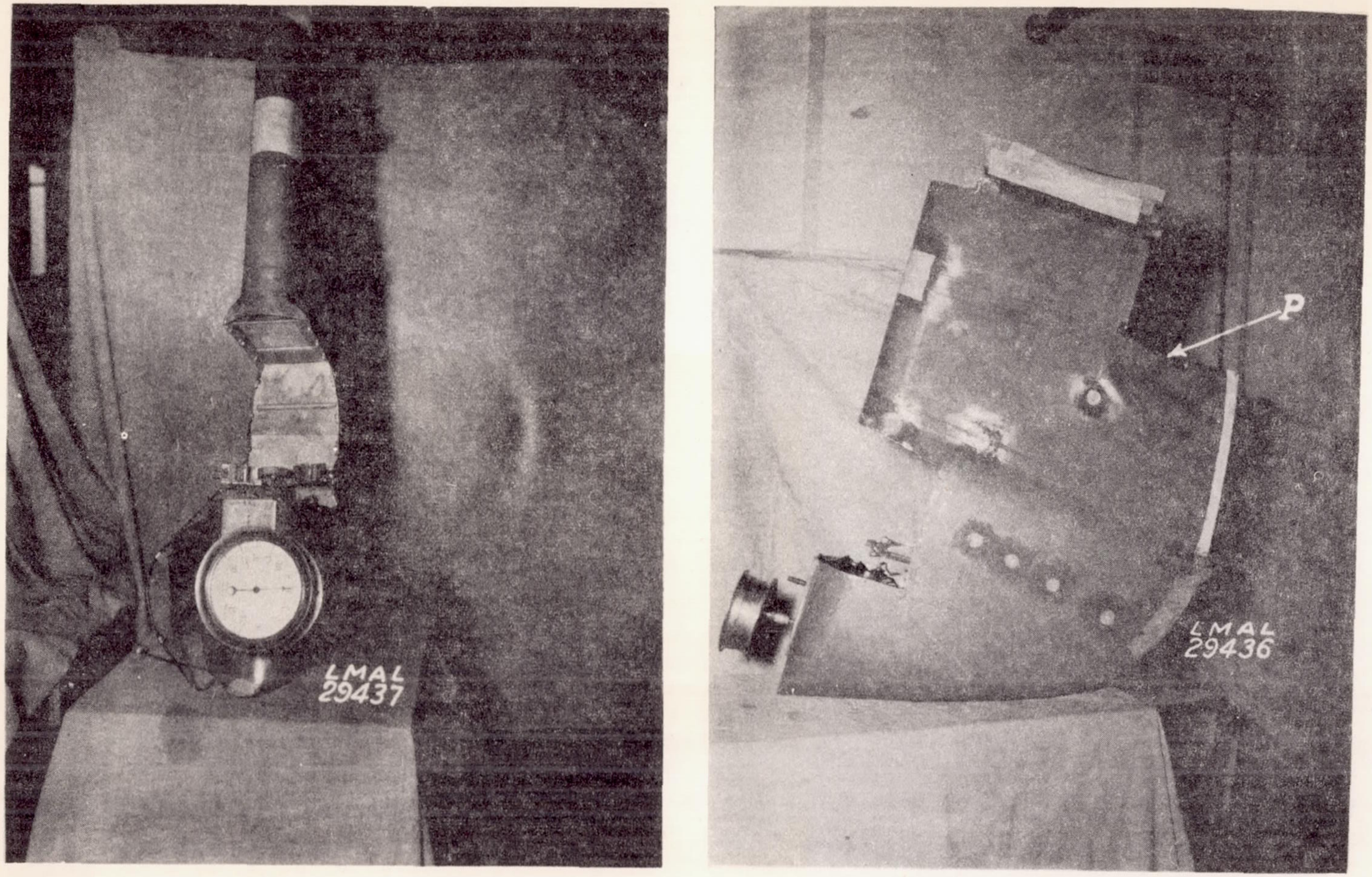


Figure 32.